MECHANICAL ENGINEERING

August 1936

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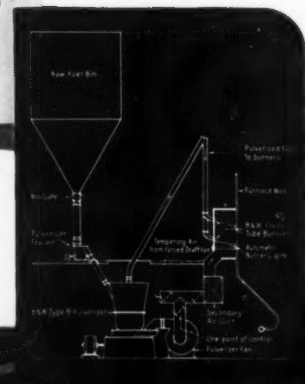

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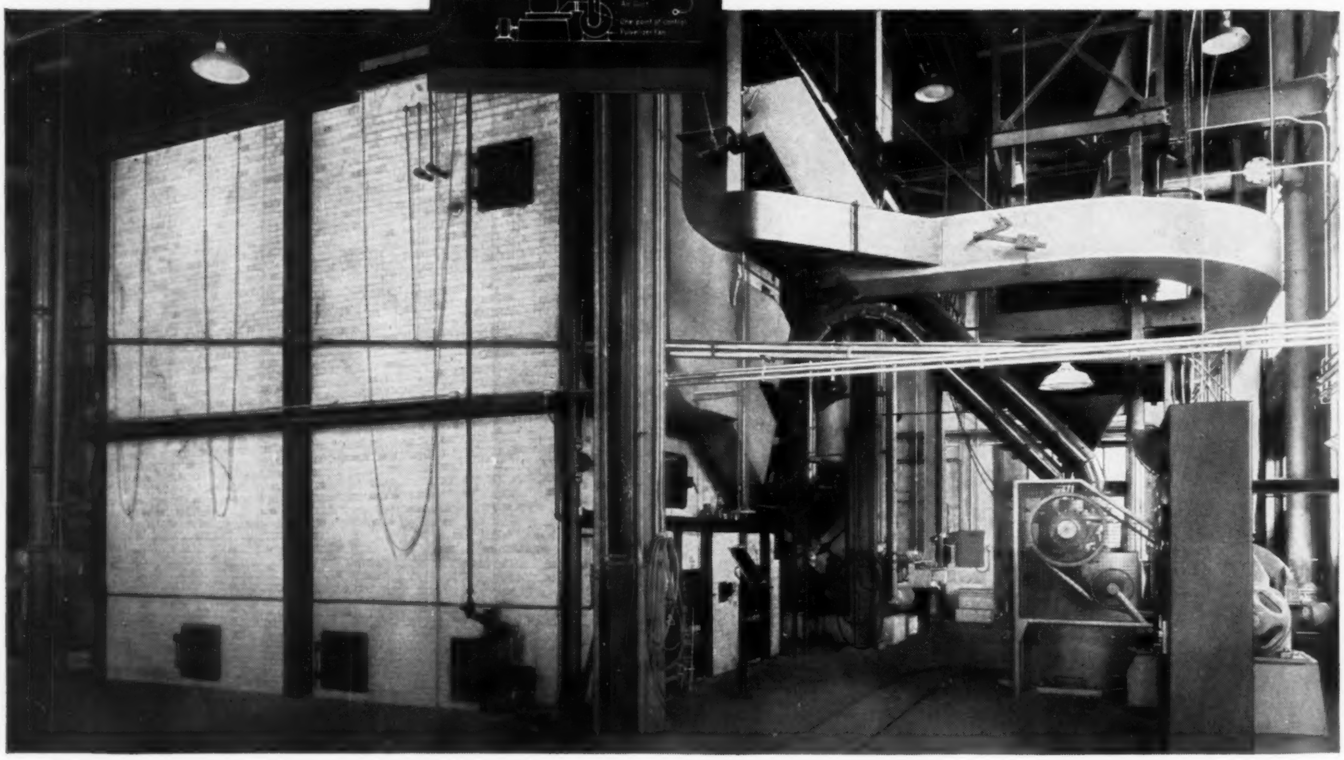

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Gerald Young

The Pattern Maker

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MECHANICAL ENGINEERING

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GEORGE A. STETSON, *Editor*

Education of the Engineer

WE ARE fortunate in being able to present, through the courtesy of the Commissioner of Labor Statistics, the first of a series of studies of the data recently accumulated by that Bureau, in cooperation with the American Engineering Council, relating to the status of engineers during the years of the depression. This first study is confined to the education of the engineer. The results confirm those arrived at by other studies and are succinctly summed up by Andrew Fraser, Jr., author of the report, as follows:

"A first degree in engineering is now almost a prerequisite in order to obtain professional status and a position. Postgraduate work, however, is important only in a few of the professional classes. The tendency of engineers to transfer from the course of college specialization to other classes of work is negligible."

Realizing that such studies are of universal interest to engineers, particularly as many thousands of our readers of Mechanical Engineering filled out the statistical blanks on which the results are based, a liberal abstract of the text and tables of the report on education is presented on pages 505–509.

Other studies of the data are to be made available from time to time, and it is hoped that the results will be presented in Mechanical Engineering.

Guidance Activity in Detroit

LAST month we called attention to the vigorous junior movement of the Providence Engineering Society in which the Engineers' Council for Professional Development was a helpful factor. This month it is possible to report another case in which the council has been able to render to the city of Detroit a service that holds promise of fruitful consequences.

With the inspiration and assistance of the Committee on Student Selection and Guidance of the E.C.P.D., a committee of the Associated Technical Societies of Detroit conducted a practical demonstration of guidance methods for high-school boys contemplating the study of engineering. After months of careful preparation the Detroit Committee, under the chairmanship of Clement J. Freund, dean, College of Engineering, University of Detroit, member, A.S.M.E., representing the twelve constituent groups of the Associated Technical Societies, with the support of the Board of Education, held a public meeting, attended by 220 persons, including 123 boys. The presiding officer, E. A. Danse, chief metallurgist, Cadillac Motor Car Company, explained the purpose and plan of the meeting. Copies of "Engineering—A Career, A Culture," were distributed, and the principal address, expository of the engineering profession and its major branches and functional activities, was delivered by C. F. Hirshfeld.

For more effective presentation and to provide opportunity for personal interview, all present adjourned after Mr. Hirshfeld's address to the several conference rooms. Here counselors, who had been selected, organized, and instructed as representatives of the branches of engineering covered by the groups comprising the Associated Technical Societies, gave further brief talks and answered questions. Personal and private interviews between counselors and students followed.

The success of the Detroit venture may be attributed to the careful planning and the hearty cooperation extended by all parties to it—the Associated Technical Societies, the Board of Education, the Committee on Student Selection and Guidance of the E.C.P.D., and the numerous individuals who acted as speakers and counselors at the meeting. Similar guidance meetings may be profitably undertaken in other cities. To conduct them is a useful function of the local sections of national engineering societies. Moreover, the Detroit experience demonstrates the value of the E.C.P.D. as an advisory body, stimulating other groups to action, supplementing and assisting their work, and not taking it over or supplanting it.

Probability

IT WAS quite without design that Professor Burdell's review of Charles A. Beard's book on the nature of the social sciences appears in this issue with Mr. Hirshfeld's Birmingham address on the engineer of today and tomorrow. Certain passages quoted from Doctor Beard's book constitute such an admirable supplement to what Mr. Hirshfeld had to say about the study of social problems that the two might well be read together. Both writers take pains to point out that dependable results are much more easily obtained in the case of research in the physical sciences than they are in studies of the so-called social sciences. It would seem that this point needs little emphasis, yet so many persons who should know better disregard it that it is natural to press it further.

Faith in the efficacy of the scientific method of investi-

gation is embodied in engineers. Naturally endowed with practical mindedness, as most of them are, they are subjected to further training in the factual, realistic approach by all of the studies and methods of study of their education. As apprentices they participate in sure, nonspeculative, and effective works that produce concrete results that cannot be ignored by skeptics or the ignorant. Their predicted results follow as inevitably as the seasons; and because of this it is not surprising that they sometimes are short-tempered and intolerant with those, working on more complex problems, whose solutions go wide of the mark and whose apparently sound theories are so frequently upset. Too frequently they give the impression that if they were to attack these more subtle questions they would find the rational answers that the blundering statesman, economist, or sociologist misses.

Against this overbearing sense of superiority Mr. Hirshfeld raises his voice; and both he and Doctor Beard offer reasons why solutions are so elusive where men, rather than inanimate materials and forces, are concerned. Engineers will do well to ponder these differences in the two fields of human experience represented by these two great groups of sciences. Before they make themselves ridiculous and bring discredit on their profession by announcing fantastic panaceas in the realms of politics and economics, engineers should develop a livelier appreciation of a universal principle that works in a majority of cases in their favor and, conversely, raises mischief with the predictions of their less fortunate colleagues at work in other fields. This is the principle of probability.

When the engineer makes calculations based on the strengths of materials or the pressure-temperature relations within a gas, he is on pretty safe ground. In either of these simple cases the individual molecule of the substance involved bears so infinitesimal a relationship to the number of other molecules making up the mass that its idiosyncrasies are ineffectual in determining mass behavior. On the other hand, a single madman, destroying the head of a government, may disturb the peace of the entire world and set at naught the plans, and irrevocably alter the destinies, of millions of persons.

These two simple and imperfect examples open up endless speculation which cannot be gone into at the present moment and they are merely called forth in an attempt to emphasize this principle.

If the principle is of such significance, then, why do we not make more use of it? The evidence is that we are making increasing use of it and that by its application we are bringing about a better appreciation of what is really involved in the social as well as the physical sciences, finding a powerful tool for molding human development through both of these means.

Also without design this month's issue provides, fortunately, two examples of the intelligent use of the principle referred to, one in the realm of the more strictly physical and the other bordering on that with which the social scientists must deal. They are Professor Karapetoff's paper on Bose's quantum statistics and the contributions dealing with machine interference. Professor Karapetoff is considering the realm where the infinitely small becomes enormously great and develops a method of study of commonplace mechanisms with which young engineers will find it necessary to become increasingly familiar. Messrs. Wright and Duvall, on the other hand, attempt to set up reliable means of predicting what at first sight seems to be the unpredictable—the optimum number of machines, each subject to hazards of sudden interruption, that a man can attend.

To make a broad generalization based on the contributions referred to, therefore, it may be said that in the realm of the purely physical sciences we are finding an increasing number of cases where it is necessary to understand the laws governing the behavior of particles, while in industry we are learning to use most effectively statistical methods of analysis.

The comfort to be gained from these isolated examples in the light of what Messrs. Hirshfeld and Beard have to say is that we may hope for a more intelligent and tolerant understanding of the social sciences, as well as a more rational approach to the problems they present. Young engineers, alert to what is going on, may find themselves confronted with problems that seldom bothered their older brothers, but unless the world is doomed to an eclipse or retrogression in understanding, theirs should be great rewards in satisfaction in throwing themselves wholeheartedly into efforts to advance the broader responsibilities of the future that Mr. Hirshfeld recognizes and lays upon them.

Social Security?

NOT SO favored by blind chance as in the case of the contributions referred to in the foregoing comment, we did not have an opportunity to supplement Mr. Hirshfeld's views on social security by the address delivered by Winthrop W. Aldrich before the Institute of Public Affairs at the University of Virginia.

Mr. Aldrich's address, which was quite extensively summarized by the press, voiced the fear that legislative attempts to establish social security might prove disappointing, be fiscally unsound, cost more than we are willing or able to pay, and arouse the resentment of those who are presumed to be the beneficiaries.

Although these points are problematical and controversial, they may be raised out of respect for time-honored maxims cautioning prudent study before action, looking before leaping, and wishful thinking. They give point to Mr. Hirshfeld's comments on the value of a study of the history of human institutions, not with a view of setting up a defeatist's philosophy but to avoid the repetition of disappointments that have brought previous attempts to frustration. If engineers are to assume a wider participation in social and economic questions as they are so frequently urged to do, their approach to these questions ought not to be in a spirit of disregarding facts distasteful to their nobler and more human instincts, that would discredit them if applied to engineering problems. The effects of decisions relating to social security are too important to be arrived at blunderingly, and the decisions must be made.

The ENGINEER *of* TODAY *and* TOMORROW

By C. F. HIRSHFELD

DETROIT EDISON COMPANY, DETROIT, MICH.

THE ENGINEER has already done a perfectly marvelous job of making materialistic inventions. His contributions of tools and of organization for their use have been the means by which man has extended himself in many respects. He has extended his puny strength, the length of his arm, and the reach of his voice. But all of the time during which the engineer has been doing these things he has been creating social and economic problems of new types and of real significance. Few persons have addressed themselves properly to the solution of these problems, but we are now arriving at the point in our cultural development where we realize that they must be solved if the works of the engineer are to succeed in producing the greater and better civilization that we believe is attainable.

As an example of the need for comprehensive study and appraisal of such problems, I might cite what is now known as technological unemployment. If you will look back in English history you will discover that every time any device was produced for making things mechanically instead of entirely by hand, people argued against it because of the resultant technological unemployment. Admittedly these early objectors did not use our present-day terminology, but they all described the same disease. The human race has survived these periods of threatened technological unemployment and each time has lived to pass on to better living conditions as a result of mechanical inventions.

The history of the last forty-five years disproves the contentions of those who are alarmed over what they call technological unemployment. In 1890 this country had a population half what it had in 1927, 1928, 1929, the boom years. The introduction of production equipment in factories started on a large scale in 1890 and has continued at an ever-increasing rate ever since. If you will examine census figures you will discover that before the present depression a larger proportion of the total population was gainfully employed in the United States than in 1890. Moreover, between 1890 and 1930 there was a marked swing from agriculture to urban residence and occupations. These facts do not spell technological unemployment to me. I could give other examples that have been cited as accusations against the engineer and show you that each of them falls down upon careful analysis.

However, I say to you in all sincerity that I think the engineer has ignored a very important responsibility and still continues to do so. In a very short period of time the engineer has turned our civilization upside down, but he has not thought it incumbent upon him to offer to solve or assist in solving any of the problems which his works have introduced. Those of you who are fathers realize a certain responsibility to your offspring upon which it is not necessary for me to enlarge. But when it comes to your mental offspring, the children of your brain, you toss them out into the world and assume no further responsibility for them. If your son gets into a jam you try to help him out. If the offspring of your brain gets into a jam you say, "That is for somebody else to straighten out; the technical development is as far as I go."

I do not believe you can longer maintain this attitude.

THE ENGINEER MUST LEARN TO INTERPRET HIS WORK TO OTHERS

I do not want to be an alarmist. I do not want to give the impression that we are on the edge of a cliff and just on the verge of crashing down. I do not believe we are headed for a plunge in which we are going to lose our civilization and culture, in spite of what politicians and some others tell us. But, I do feel we are heading for some terribly difficult experiences if the engineer does not now begin to interpret to his fellow creatures the real meaning of his works.

How many engineers, for example, have taken the trouble to check up on this question of technological unemployment? Aren't we the people, as engineers, who should be preaching from the housetops the real meaning of our works? Aren't we the people who should be jumping into this discussion of technological unemployment and giving it authentic interpretation? Aren't we the people who should be gathering from sources that are already established the facts to show what our works really have done for humanity? I have tried to do it in a small way. So have a few other individuals. But the job ahead is big enough to engage the attention of all engineers. To my mind, the interpretation of our works in their social and economic connotations is now a lot more important than the making of further materialistic or technological developments. I say this to you as an engineer; as one who has the same mental make-up, the same urges, and the same limitations as have you to whom I say it.

There are few of us. In the United States Census of 1930 some 220,000 individuals declared themselves to be engineers. Probably only 120,000 to 125,000 of these persons are engineers according to our interpretation. Out of a population of about 125,000,000 probably only about 125,000 are engineers. The engineer must be a peculiar sort of specimen if he is so rare.

One of the outstanding characteristics of the engineer is that his thinking is factual. When the engineer attacks a problem in his line, he reasons as follows: "What are the facts?" "Where do they lead by a logical process of reasoning?" He does not want to make estimates or assumptions until he is absolutely driven to it. When he is, he makes assumptions knowingly and he says to himself, "That assumption will mean a possible error of plus or minus so much in my final result." And when he gets his answer, he says, "That answer is not necessarily correct, it may be in error by plus or minus so much." Where is there anybody else in our population, other than the scientist, who works in that way? I know of none.

As an opposite case, the minister of the gospel works largely upon a set of written words which have been passed down from

An address delivered before the Engineers' Club of Birmingham, Ala., April 15, 1936. Abridged.

father to son. The lawyer works in much the same way, except that the written words are amended from time to time by the courts. Both are dependent on precedent. How many engineers act on the basis of precedent? They do not get very far if they act entirely on it. I am not setting the engineer up as superior to the minister or the lawyer. He has work of a different type to do and he has to do it by a method adapted to the needs of the situation. These 125,000 engineers all think in a peculiar way when compared with practically all of the rest of humanity. They speak a language based upon their thought process and unknown to almost all their brothers who are engaged in other types of pursuits. Therefore the engineer has a real task ahead of him if he is to attempt to interpret his works to the rest of humanity.

You have heard the doctors use Latin terms, and lawyers use Latin terms, and you probably have wondered why under the sun they didn't speak in English. Our engineering language to the common run of humanity is just as mysterious as the Latin used by the doctor or the lawyer.

Let me try to give you a single example.

If a man comes to you with a scheme for perpetual motion, you say to him, "That is perpetual motion. That cannot be." That is the end of your argument. To you it is quite sufficient. He does not recognize the situation at all as you do. He believes that perhaps perpetual motion can be. How do you go about explaining to him your reason? Do you realize that you have to take him back to the very fundamentals of science that he does not know in order to explain? I could cite other examples. You just naturally start thinking and talking in a way very different from that used by the much larger part of the human family.

I suggest to you an experiment. I suggest that in some gathering of a social type you look around and observe how many engineers are talking to anybody other than engineers. You will be surprised to find how few are. Why? Are the others less intelligent? I do not think so. But engineers cannot talk with their fellow beings easily unless they too are engineers. There is a reason. The engineer's method of thought and the engineer's language are so different that he becomes uncomfortable when he is required to talk in social gatherings what he regards as "small talk" and for which he has no particular aptitude. He loses patience when he tries to tell another individual something the latter does not and cannot understand. He is inclined to belittle the mental capacity of the other fellow merely because it happens to be different from his own.

The time has come when engineers must learn to talk the language of their fellow beings, other than engineers, so that we can talk to them in words that they can understand. The time has come when we must make it our business to find ways and means of explaining to the masses the real significance of our works. The time has come when we must begin to educate ourselves to the ability to think about the nontechnical problems faced by humanity.

Assume that we learn to speak the language of the other fellow and that we prepare ourselves properly for the interpretation of our own works and for the study of social and economic problems. What are we to do then? I am certain that we should not start out to solve all of the problems of the universe. We shall still be engineers and very few engineers are going to be successful politicians, lawyers, or spellbinders. But we can be very useful if we will only prepare ourselves along the lines just indicated. We can learn gradually how to interpret our works in terms of economic and social significance, and I think we shall soon discover that, if we will only give our fellow citizens the rights and wrongs of such questions, they will accept them from us because they recognize us as individuals who tell the truth.

Have you ever heard any responsible person question the probable performance of a work of engineering? When the engineer undertakes the putting of a bridge across a river, the public does not doubt a successful outcome. The newspapers do not question whether the engineer can do it. Can you point out any other proposal that is made that is accepted in that way, except religious matters that are accepted on faith? For that very reason when we do explain to the public the real significance of our works I expect that public is going to believe us.

Do you not realize that you carry a tremendous responsibility on your shoulders? You have tossed your brain children into the world to turn civilization upside down in many respects, but you have felt no responsibility for helping the world to assimilate them. Nor have you endeavored to assist in the making of social and economic inventions leading toward a better balanced society. Technologically, we have risen far; socially and economically, I fear, we are far behind our technical advances.

A STUDY OF HISTORY PROVIDES THE MEANS OF UNDERSTANDING SOCIAL PROBLEMS

I have spoken of material inventions. The present Federal Administration has said much about a social invention called social security. As a matter of fact, this is a very old invention. It goes back at least to Biblical times. If you will read Biblical and Roman history carefully you will find many examples of social-security legislation. You will also find that attempts to utilize many of these social-security inventions have ended disastrously. That seems all wrong to a humane human being who is moved by sympathy. It would seem that we should be able to improve greatly the circumstances of our less fortunate fellows. However, there appears to be a rigid rule of nature that makes conditions otherwise. As I read history it appears to me that whenever social security has become so much of a political question that it has been forced too far ahead of the social and economic development of mankind at the time, it has ended disastrously. Mankind has certainly progressed toward better things and greater distribution of opportunity and wealth through a series of social inventions, but there appears always to have been a brake upon the too rapid utilization of such inventions. This brake is certainly in part the ability to pay the bill. This was noticeably true in the case of the old Roman Empire. I think we are going to find it true in our present civilization.

The present tremendous drive toward greater social security is not local. It is a world-wide phenomenon. It appears in different guises in different countries, but in all of the other advanced countries of the world you will find this same agitation for greater social security. It must mean something. It does mean something. But I am afraid that in many respects it is, in a sense, an unfortunate drive which is doomed to failure because we have not yet learned how to pay the bill for a much greater degree of social security than is now to be had in this and some other countries.

During the past 40 years we have made greater advances in the direction of social security than ever before, and in nearly all instances this has come with greater technological development. Technological development has produced the wherewithal to pay the bills for better conditions and for greater social welfare for the lower strata of humanity. Again, is it not incumbent upon the engineer to dig out these facts, if they be true, and to put this question on a factual basis? Should he not be prepared to say to his fellow men, "These are the facts; the lower strata of society should have all

those things that make for pleasant life, but bear in mind that we cannot provide them until we have learned how to make production pay for them."

When your fellow man begins to understand a real problem he generally thinks and acts correctly. Determine what the facts are, then preach them among your fellows, not for political purposes but to produce a greater understanding of the conditions under which we live and in the hope that by such means we may more concertedly and certainly drive toward a greater and better end.

Some of us have had an idea of this general sort for quite a long time. But we have been handicapped by the unpreparedness of the engineer for work of this sort. How many of you know much about economics? How many of you know much about social science other than the handling of men in your own business? How many of you know much about the history of the human race? Many of you once studied history. You were taught certain dates, when certain kings were crowned, when certain battles were fought, and who won and who lost. Very few of you have ever studied history as a record of the economic and social growth of the human race.

As engineers you have learned the experimental method, by taking things into laboratories and testing them. If you want to learn the properties of a metal, you take it into a laboratory and subject it to various kinds of tests. When you have finished you have the data which show how to use this metal for certain purposes. Similarly, if you want to learn the laws of the pendulum you may set one up in a laboratory and study it experimentally until you have determined the laws that govern its operation. However, when you come to consider human beings you discover they are different. The minute you take a person into a laboratory for the purpose of testing him you have created abnormal conditions. The subject is changed in some subtle way. The results you obtain are not indicative of the behavior of the normal human being in the same sense that the results obtained with metal are indicative of the normal behavior of that material. To make matters still worse, social inventions affect millions of persons, and you certainly cannot experiment in a laboratory with groups of such size.

Your first reaction is likely to be a feeling that you cannot find out anything about these human beings. But in reality a tremendous experimental record is available to you. Human beings have been experimenting with themselves and with their social and economic organizations at least as long as there has been a historical record. The only way you can now study human beings as you have learned to study materials and mechanisms is to study this record extending through the ages. In this way you can put economic and social study on a very practical basis.

I have tried it. I have studied history in this way and I find it wonderfully helpful. It gives an insight into the expectable reactions of human beings which cannot be obtained in any other way that I know. It gives a knowledge of many attempted applications of social inventions which is exceedingly useful in attempting to evaluate what are supposed to be new suggestions. He who knows the history of human experience speaks with much greater authority than does he who merely wishes or guesses.

This method is not foolproof. Conditions today may be different from those existing during an earlier experiment. And it is difficult to determine what are the controlling factors. When you test a piece of metal in the laboratory you can control the temperature, the rate of applying load, and all other factors affecting the result. When you attempt to study the behavior of humans, all you can do is to attempt to formulate the behavior of a set of human beings under given conditions. What were the given conditions? Out of the great multitude existing at any one time, which were controlling and which merely contemporaneous? Your conclusions will be correct only as you succeed in eliminating unnecessary factors from consideration.

If you will do your work carefully, you will find that in a gross sort of way you can interpret history in the terms of social and economic movements and that that interpretation will act to put your thinking on a more factual basis than has, in general, existed in those fields.

If you talk to workers in the economic and social fields you will find they are quite proud of the fact that they have adopted the scientific method of studying their problems. They say, "Here is the scientific method of approach, and this line of reasoning must be correct." I do not believe that in many cases they do use a truly scientific approach to those problems. You cannot determine in the space of a few years the significance of a given major social movement. The question of technological unemployment has been particularly prominent during the last few years, but we have had technological development for about two and a half centuries, and the question of technological employment has bobbed up from time to time during that entire period. It is necessary to go back to earlier ages and to consider a long period of time to make a satisfactory study of the problem.

E.C.P.D. AN EVIDENCE OF SOCIAL CONSCIOUSNESS IN ENGINEERS

For some time a few of us have thought that the time was right for the engineer to study social and economic problems as *part* of his work, not *instead* of his present work. As an entering wedge we organized what is known as the Engineers' Council for Professional Development. It is a small beginning, but it has two very definite and I think worth-while objectives; one, to constitute a single organization through which the engineers of this country may cooperate successfully, and the other to build up that kind of engineer who is prepared, who is capable of undertaking the kind of work the engineer in the future must do in addition to the kind of work he has done in the past.

This Council has a membership of seven bodies. Five of them are technical engineering societies: American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, The American Society of Mechanical Engineers, American Institute of Electrical Engineers, and American Institute of Chemical Engineers.

One of the remainder is the Society for the Promotion of Engineering Education, and the seventh is the National Council of State Boards of Engineering Examiners. The technical engineering societies represent the technical, and to some extent the social, aspects of the engineer's life and work. The S.P.E.E. obviously represents the educational aspect. The board of engineering examiners represents the legal aspect. These constitute E.C.P.D. This council was instructed to determine the ways in which the professional stature of the engineer might be developed and how engineering in its broadest conception might be advanced. It has no charter to do anything other than that. It studies means and procedures and reports its recommendations to the parent bodies. These bodies may or may not accept the recommendations. They may accept them and instruct E.C.P.D. to carry them through, or they may accept and provide other means of instrumentation.

The council now has four active working committees as follows: The first is known as the Committee on Student Selection and Guidance. It attempts to devise ways and means of helping boys who think they want to study engineering. It un-

dertakes to provide means of showing them what engineering really is, to help them determine whether they can profit from an engineering education, and to help them in the selection of a course and a college.

The second committee is known as the Committee on Engineering Schools. It does not attempt to tell teachers of engineering how to teach engineering. It realizes that the teaching of engineering is in a continuous state of flux. It hopes that by bringing together prominent and thinking industrial leaders, practicing engineers, and educators it may assist in developing better engineering courses, better methods of teaching engineering, and, ultimately, better engineers.

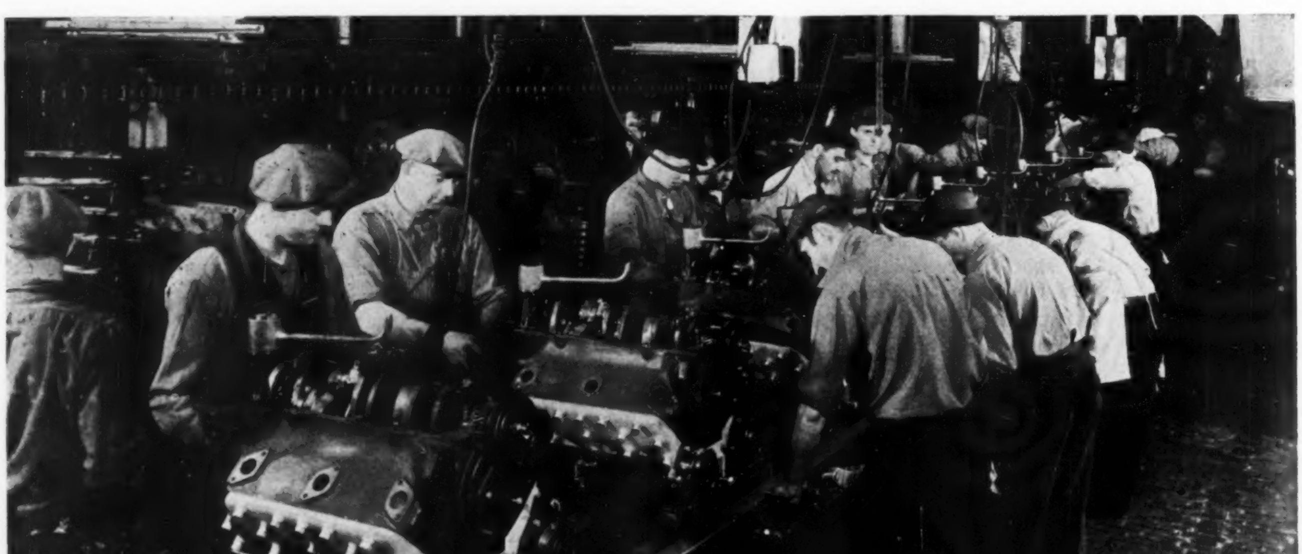
This committee also deals with the accrediting of schools of engineering. Most states have adopted engineers' license laws. These laws almost always include graduation from an accredited school of engineering as one way of determining the man's fitness to be licensed. The people who passed these laws probably never gave much thought to what they meant by "accredited schools of engineering" and how such schools were to be determined. The boards charged with the licensing of engineers had to find some way of obtaining lists of accredited schools of engineering. Some few have undertaken to prepare such lists for themselves, but in most cases this is too costly a procedure. When E.C.P.D. suggested that it might do the job, the national organization of the state boards of engineering examiners was glad to turn it over to them. The council is now engaged in accrediting schools in the New England and North Atlantic states. This is being done first to determine how the adopted mechanism works. As soon as this part of the job is sufficiently advanced, E.C.P.D. will start on the engineering schools in the rest of the country.

The third committee, known as the Committee on Professional Training, deals with the education of an engineering graduate from the time he leaves school until he measures up as a full-fledged engineer; that is, a man who is competent to practice in his own right. When this time arrives, the man should rate full membership in a major engineering society and should be capable of obtaining a license in any state requiring registration as a prerequisite to practice. Such post-graduation education is no easy task. The young engineer is usually employed in an apprenticeship and has the technical side of the job ever before him. He hopes to rise rapidly and has a tendency to concentrate too narrowly for his own good. We are trying to give his development better balance. We are trying to interest him in literature, philosophy, sociology, economics, general science, and history; in short, to make a balanced individual of him. We hope that when he becomes available for consideration for a minor executive position he will have gone some distance toward becoming a real member of the community.

Running parallel with this is the development of men who have not had the advantage of a college education. Realizing that shortly these men will not be allowed to obtain a license unless they can pass a technical examination equivalent to that given college graduates, we have set ourselves the task of assisting these men to obtain the required education.

The fourth committee, known as the Committee on Professional Recognition, concerns itself with those things having to do with the recognition of achievement. It is endeavoring to bring about a general unanimity in what may be called the "minimum definition of an engineer." It hopes that ultimately the state boards, the engineering societies, and others may be able to agree upon that measure of ability and accomplishment required for certain types of recognition.

All of this is merely the mechanics of an attempt to produce in the future the kind of engineer that we now realize we should have been. We now recognize some of the limitations under which we work as members of the community in which we live and we are trying so to arrange matters that the engineers who come after us will not be so handicapped in their communities. To our mind, no man is an engineer unless he has a solid training in the fundamental sciences and in their application to the solution of engineering problems. We are not trying to make a less technical engineer, as some people are trying to do. We are still trying to make real engineers in the old-fashioned sense, but we are trying to make them not only materialistic but human engineers who are willing to take upon their shoulders part of the world's burdens in attempting to solve pressing human problems. They are never going to displace trained men who are already working in the social, economic, and political fields, but I think they are going to become very useful in assisting such workers.



FORD ASSEMBLY LINE—ATTACHING OIL PAN TO ENGINE BASE

FLUID FLOW *Through* TWO ORIFICES *in* SERIES

By MILTON C. STUART[1] and D. ROBERT YARNALL[2]

Two orifices arranged in series may serve as a control element by utilizing the variations in pressure which occur in an intermediate chamber located between the two orifices. The intermediate pressure existing between two orifices depends upon the nature and properties, particularly the temperature and phase, of the fluid flowing. Cold water and water at temperatures far below the saturation temperature produce relatively low intermediate pressures. Steam, saturated water, and hot compressed water flowing through two orifices in series produce relatively high intermediate pressures. It is this phenomenon which becomes the basis for a control element in which the varying pressures in the intermediate chamber are used to actuate a piston or other pressure-sensitive device, and thus control flow, temperature, or pressure.

This paper presents an explanation of how the intermediate pressure between the two orifices of the control element depends upon the temperature and phase of the water supplied. This requires first a study of the characteristics of the flow of saturated liquid water and compressed liquid water at various temperatures through single nozzles and orifices. This study, which is presented in an appendix to this paper, shows that for the purpose at hand the nozzle flow of saturated and high-temperature compressed liquid water is characterized chiefly by high critical-pressure ratios. This and other characteristics of single-nozzle flow will be referred to as required. We now proceed directly to the explanation of the action of the series orifices, particularly as concerns the variation of the intermediate pressures.

DETERMINATION OF FLOW CHARACTERISTICS

As an introduction to the development of the series-orifice flow characteristics it may be stated that the intermediate pressure P_x between two orifices, arranged as shown in Fig. 1, is fixed at a unique value which will satisfy the condition of equal mass flow through the two orifices.

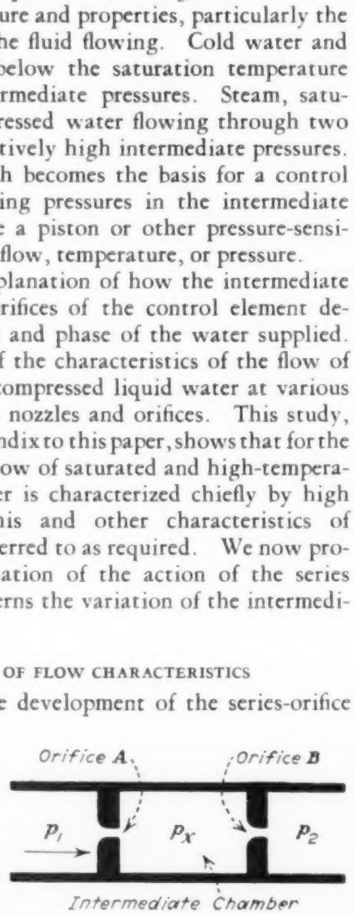


FIG. 1 ARRANGEMENT OF TWO ORIFICES IN SERIES

This intermediate pressure, being common to both orifices, is influenced by the separate flow characteristics of each orifice for the particular state of the fluid flowing. A convenient graphical solution determines the intermediate pressure by the intersection of flow-characteristic curves for the two orifices. The method is applied to determine the series-orifice characteristics for the flow of cold water, saturated steam, saturated water, and compressed water, in Figs. 2, 3, 4, and 5, respectively.

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[2] Yarnall-Waring Co., Chesnut Hill, Philadelphia, Pa. Mem. A.S.M.E.

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For each of these figures curve *A* shows for orifice *A*, with a constant entrance pressure of 100 lb per sq in. absolute, the rate of flow which would exist for a range of assumed intermediate-chamber pressures disregarding any possible effect of orifice *B* on the flow. Curve *B* shows the rates of flow for orifice *B* for a range of assumed intermediate pressures and a constant discharge pressure of 15 lb per sq in., but assuming the fluid has been throttled through the first orifice. Thus the enthalpy in the intermediate chamber is properly taken as equal to that at the entrance to the first orifice. Curves *A* and *B* are plotted to a common abscissa of the assumed intermediate pressures and to a common ordinate of rates of flow. Since during series flow there must exist a common intermediate pressure and a common rate of flow, the intersection of curves *A* and *B* locates the required intermediate pressure and the common rate of flow.

That portion of curve *A* from P_1 to P_x covers the flow characteristics of orifice *A*. By flow characteristic of an orifice is meant the curve showing rates of flow which would exist for the constant entrance pressure and variable lower pressure as indicated by the abscissa. Curve *C*, which is a corresponding flow characteristic for orifice *B*, shows the rates of flow which would exist through the second orifice with the constant entrance pressure P_x and exit pressures ranging from P_x to P_2.

The most significant feature disclosed by Figs. 2, 3, 4, and 5 is the variety of intermediate pressures P_x occurring for the various conditions of the water flowing through the two orifices. These intermediate pressures range from 57.5 lb per sq in. for cold water, to 96.0 for saturated water. This variation may be attributed chiefly to the effect of the critical-pressure phenomenon upon the characteristics of the orifices with the various water conditions.

It is recalled that the critical pressure for flow is defined as that minimum pressure to which an expansible fluid will expand in a convergent channel connecting a high- and low-pressure region. Cold water being practically inexpansible, exhibits no critical-pressure phenomenon. The flow characteristics for cold water are identical for both orifices as shown by curves *B* and *C* in Fig. 2, and the intermediate-chamber pressure P_x is midway between the upper pressure P_1 and the lower pressure P_2.

With saturated steam and saturated and compressed water, however, the critical-pressure phenomenon exerts an important influence upon the orifice characteristics, both singly and in series. In Figs. 3, 4, and 5 for saturated steam, saturated liquid water, and compressed liquid water, respectively, the critical pressures for the two orifices are indicated at the points marked P_c. In each case, the critical pressure of the first orifice is lower than the intermediate pressure, which is the discharge pressure for orifice *A*. For the second orifice, however, the critical pressure is in each case higher than the discharge pressure for that orifice. It will be shown directly that this has a predominating influence on the system characteristics.

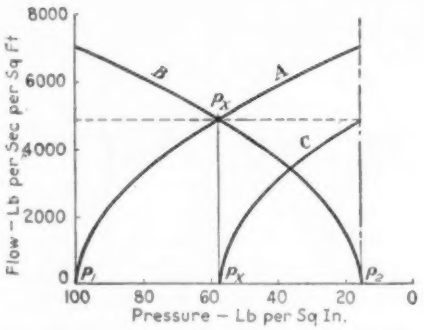


FIG. 2 CHARACTERISTICS OF FLOW OF COLD WATER THROUGH TWO ORIFICES IN SERIES

(Initial pressure 100 lb per sq in.)

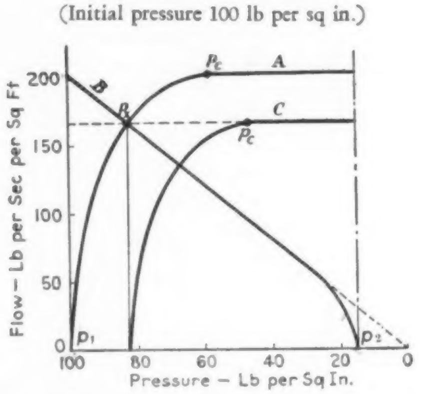


FIG. 3 CHARACTERISTICS OF FLOW OF SATURATED STEAM THROUGH TWO ORIFICES IN SERIES

(Initial pressure 100 lb per sq in.)

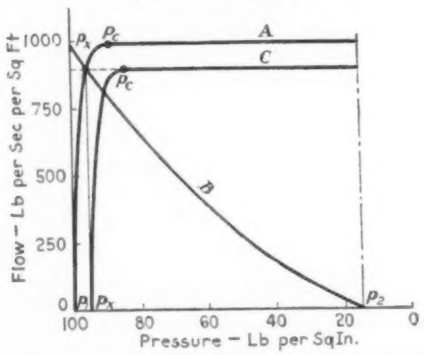


FIG. 4 CHARACTERISTICS OF FLOW OF SATURATED LIQUID WATER THROUGH TWO ORIFICES IN SERIES

(Initial pressure 100 lb per sq in.)

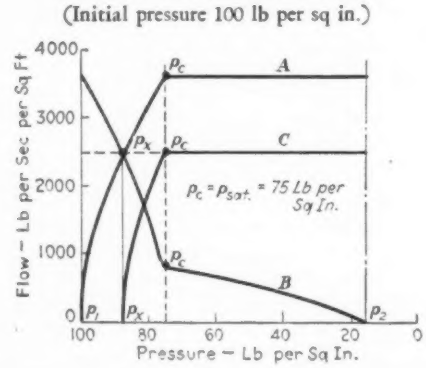


FIG. 5 CHARACTERISTICS OF FLOW OF COMPRESSED LIQUID WATER THROUGH TWO ORIFICES IN SERIES

(Initial pressure 100 lb per sq in. abs subcooled 20 F.)

FLOW OF SATURATED STEAM THROUGH TWO SERIES ORIFICES

Considering in detail the flow of saturated steam through the two orifices as shown in Fig. 3, curve *A* for orifice *A* is the well-known characteristic for flow of steam through a nozzle with a constant entrance pressure and a variable exit pressure. As the exit pressure decreases flow increases till the critical pressure is reached at a value of approximately 57 per cent of the entrance pressure. For exit pressures below the critical the flow remains constant. Curve *B* for orifice *B* shows flow for a constant exit pressure of 15 lb per sq in. and a variable entrance pressure. It is essentially the curve representing the classical Napier formula for flow of steam which expresses the approximate relationship that steam flow is proportional to entrance pressure, when the exit pressure is below the critical pressure.

The intersection of curves *A* and *B* fixes the intermediate pressure at 83 lb per sq in. This results in a pressure drop of 17 lb per sq in. through the first orifice, and a drop of 68 lb per sq in. through the second orifice. Thus the pressure drop through the second orifice is four times the drop through the first orifice. Part of this large pressure drop through the second orifice is caused by the larger pressure drop required for the flow of the less dense fluid through the second orifice. A glance at the critical-pressure points on the curves shows, however, that the critical-pressure phenomenon is an important factor in causing the high intermediate pressure.

FLOW OF SATURATED AND COMPRESSED LIQUID WATER

This effect of critical pressure upon intermediate pressure is still more pronounced in the case of flow of saturated liquid water through the two orifices as shown in Fig. 4. Curve *A*, the characteristic curve for flow of saturated water through orifice *A*, shows the high critical pressure of 93 lb per sq in. compared with 57 lb per sq in. for saturated steam under the same initial pressure, 100 lb per sq in. This characteristic curve for saturated water is developed in detail in the appendix, Fig. 9. The intersection of the curves for the two orifices in Fig. 4 fixes the intermediate pressure at 96 lb per sq in. Inspection of this figure shows that this high intermediate pressure is caused by the high critical pressures for flow of saturated water.

It remains to investigate the behavior of compressed water. Compressed water is defined as water under a pressure higher than the saturation pressure corresponding to the temperature or, expressed alternately, it is water having a temperature lower than the saturation temperature corresponding to the pressure. An analysis of the flow of compressed water made in the appendix reveals a characteristic phenomenon regarding the critical pressure in compressed-liquid flow, namely, that for flow of compressed liquids the nozzle critical pressure is practically the saturation pressure corresponding to the liquid temperature.

Fig. 5 gives series-orifice characteristics for compressed water supplied at a pressure of 100 lb per sq in. and a temperature of 308 F which is 20 deg below saturation temperature. Critical pressure for this compressed liquid water is 75 lb per sq in., the saturation pressure corresponding to the temperature of 308 F. The intersection of the flow curves establishes the intermediate pressure at 87.5 lb per sq in. which happens to be just midway between the entrance pressure and the critical pressure. It is noted that in the intermediate chamber the fluid is still in the compressed-water condition. Here again it is the critical-pressure phenomenon which causes the high intermediate pressure.

EFFECT OF TEMPERATURE AND PHASE ON INTERMEDIATE PRESSURE

The essential results of two-orifice flow are summarized by the curve of Fig. 6. In this curve the ordinates are the inter-

mediate pressures to be expected for the range of water temperatures shown on the abscissa. When water is supplied at temperatures below 212 F the intermediate pressure is constant at 57.5 lb per sq in. As water temperature increases above 212 F the intermediate pressure increases to a maximum of 98 lb per sq in. for water subcooled the slight amount of 4 deg. For saturated water the intermediate pressure drops slightly to 96 lb per sq in. For saturated steam the intermediate pressure is 83 lb per sq in.

The curve of Fig. 6 is the essence of the theory of the two-orifice flow-control element. This curve showing variation in intermediate pressures with temperature and phase of water has been developed theoretically to explain observed phe-

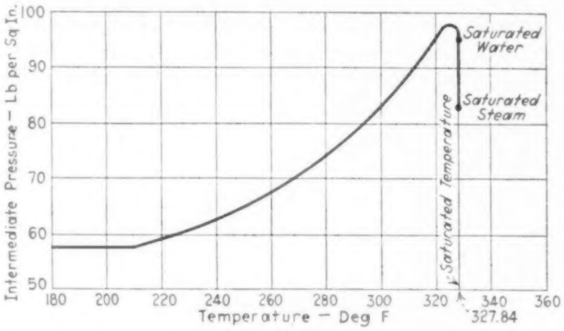


FIG. 6 INTERMEDIATE PRESSURE EXISTING BETWEEN TWO ORIFICES FOR FLOW OF SATURATED STEAM AND SATURATED AND COMPRESSED LIQUID WATER, SHOWING EFFECT OF TEMPERATURE AND PHASE ON INTERMEDIATE PRESSURE

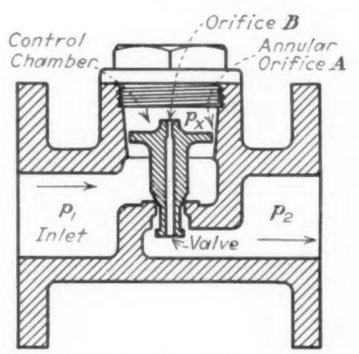


FIG. 7 CONDENSATE-DRAINAGE DEVICE UTILIZING AS A CONTROL PRINCIPLE THE CHARACTERISTICS OF FLOW THROUGH TWO ORIFICES IN SERIES

nomena. Although no experimental results are cited in this paper, sufficient experimentation has been made to confirm all the results presented. In the foregoing analyses, orifices A and B have been taken to be similar ideal rounded-entrance orifices with equal areas. Certain desired variations in the intermediate-pressure curve may be effected by changing the relative sizes of the orifices and by using for orifice A or B certain variations in form, such as a sharp-edged orifice, a nozzle with diverging section, a short tube, or other apertures, which, by virtue of their special characteristics, react to give desired characteristics to the intermediate-pressure curve.

TWO-SERIES ORIFICE AS A CONTROL ELEMENT

The two-series orifice arrangement may be used as a basis for a control element in many engineering applications by utilizing the varying pressure in the intermediate chamber to actuate a piston, diaphragm, or other pressure-sensitive device to control pressure, temperature, or flow.

A particular application which has been developed is a condensate-drainage device, a section of which is shown in Fig. 7. The fundamental principle of series-orifice flow control is embodied in this device as follows: Orifice A is the annular space between the loose-fitting control valve and the wall of the control chamber. Orifice B is the small circular orifice extending through the top of the control valve. The space above the control valve constitutes the intermediate or control chamber. The value of the intermediate pressure P_x in the control chamber is established by the temperature of the condensate flowing. This pressure controls the opening and closing of the valve in accordance with condensate temperatures.

Thus, if cold water or relatively low-temperature condensate is supplied to the inlet the control-chamber pressure will be relatively low, as shown by the graph in Fig. 6, and the excess pressure acting under the control-valve disk will cause the valve to open and permit discharge of condensate through the main valve.

If relatively hot condensate, either saturated or nearly saturated, or steam, is supplied to the inlet, a relatively high control-chamber pressure will be established, and this pressure acting on top of the valve disk will keep the valve closed.

The temperature of water at which the valve will operate may be controlled by practical features of design, including sizes and forms of control orifices A and B and the relative sizes of valve disk and valve seat.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance given in the preparation of this paper by Messrs. H. J. Everett and J. B. Lusk of Lehigh University, and J. F. McKee and W. J. Kinderman of the Yarnall-Waring Co.

APPENDIX

The development of the theory of the flow of water and steam through two orifices, presented in the paper, required a study of the flow of saturated and compressed liquid water through single nozzles and orifices. The flow of cold water and of saturated steam through nozzles is adequately treated in many places, but the characteristics of flow of liquid water in the saturated state and in the subsaturated or compressed-liquid region has not been treated in sufficient detail for the purposes of the analysis of the series orifice.

The principles, procedures, and characteristics covering the general field of flow of saturated and compressed liquids developed here are also applicable to any situations involving the flow of high-temperature, high-pressure liquids, such as, discharge through boiler blowoff valves, discharge from steam traps, throttling of high-pressure, high-temperature water in modern steam cycles, use of water nozzles or diffusers in water ejectors or turbines, and the throttling of liquid ammonia in the vapor refrigeration cycle.

NOTATION AND DEFINITION OF SPECIAL TERMS

M/A = mass rate of flow past a section, lb per sec per sq ft
U = velocity, fps
V = specific volume, cu ft per lb
H = enthalpy, Btu per lb $(E + PV/J)$
P = absolute pressure, lb per sq ft
p = absolute pressure, lb per sq in.
S = entropy
J = 778 ft-lb per Btu
Subscript 1 refers to upstream section, usually at nozzle entrance
Subscript 2 refers to downstream section
Subscript f refers to saturated-liquid state

Subscript g refers to saturated-vapor state
Subscript fg refers to vaporization change of state
Subscript s refers to a constant-entropy process

Compressed liquid is a liquid under a pressure higher than the saturation pressure corresponding to the temperature; an alternate statement is that the liquid temperature is lower than the saturation temperature corresponding to the pressure. Synonyms for compressed liquid are *subsaturated liquid* and *subcooled liquid*.

Critical point is the state of a fluid at a temperature and pressure at which the latent heat of vaporization becomes zero.

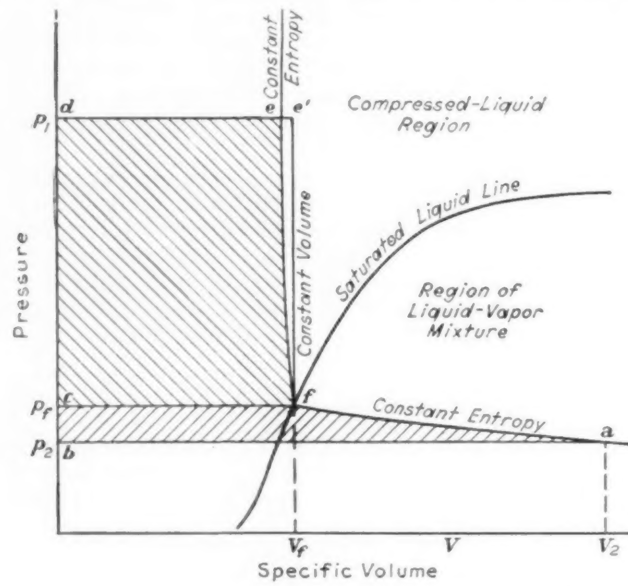


FIG. 8 PRESSURE-VOLUME DIAGRAM FOR ISENTROPIC PROCESSES WITH COMPRESSED AND SATURATED LIQUID WATER

At this point the vapor and liquid states are indistinguishable. For water, this point is at a temperature of 706 F and a pressure of 3226 lb per sq in. *Critical point* is not to be confused with *critical pressure* and *critical-pressure ratio*, described later.

Critical pressure for nozzle flow is the lowest pressure which will exist for ideal flow in the converging portion of the nozzle. It is the throat pressure of a nozzle and fixes and limits the maximum rate of flow through a nozzle.

Critical-pressure ratio for nozzle flow is the ratio of critical pressure to nozzle entrance pressure.

THERMODYNAMICS OF THE ISENTROPIC PROCESS

The novel and essential feature of the method of calculating nozzle flow for saturated and compressed liquids is the substitution for the adiabatic enthalpy drop $J\,(H_1 - H_2)_s$, of its equivalent[3] $\int_2^1 VdP$. Explanation of the necessity for this substitution follows.

It happens that flow from the saturated or near-saturated-liquid state involves small enthalpy drops, and the corresponding small numerical values resulting from the subtraction of two relatively large quantities H_1 and H_2 give rise to prohibitively large arithmetical errors. Especially are these errors large as the pressure drops become smaller, and in the region of small pressure drops, where high accuracy is essential, the errors become enormous. However, the use of the $\int VdP$ method not only avoids the necessity of the use of enthalpies, but lends itself to easily performed arithmetical solutions which give quite satisfactory accuracy.

The nature of the problem is illustrated in Fig. 8, which is a P-V diagram of reversible adiabatic processes in the saturated- and compressed-liquid region. In this figure the P-V plot of the saturated-liquid line to the critical point is indicated. A constant-entropy (reversible adiabatic) process with liquid water is shown by the line *efa; ef* being the path in the compressed-liquid region and *fa* the path of the process after passing the saturation condition *f*. The adiabatic enthalpy change for any portion of this process is $\int VdP$ for the portion, and this integral is represented graphically as the area back of the line describing the process. For the compressed-liquid portion of the process, $\int VdP$ is the shaded area *fcdef*. Since the constant-entropy process for a compressed liquid follows closely the constant-volume process, this area is closely equivalent to the area *fcde'f*, or, for the compressed-liquid region $\int_2^1 VdP = (P_1 - P_f)V_f$.

For large pressure drops, this evaluation may be made by using the enthalpy-drop method, using the enthalpies recorded for compressed liquid in papers by Keenan[4] and Berry.[5] However, the computation by the P-V method is no doubt simpler than by the enthalpy-drop method, and is of quite sufficient accuracy except for large pressure drops at the high temperatures and pressures near and above the critical point.

For expansion past the saturated-liquid state at f the value of $\int_2^1 VdP$ becomes the shaded area *abcfa*. The values of the specific volumes along the line *fa* in the wet region are computed in the usual manner. For a considerable range of pressure drops the line *fa* is sufficiently close to a straight line to permit the evaluation of $\int_2^f VdP$ by the area of the trapezoid *abcfa* which is $(P_f - P_2)\,(V_f + V_2)/2$. For larger pressure drops the line *fa* is curved and the desired area is obtained by dividing into convenient trapezoids, or by any of the rules for arithmetical integration. Further, in regions of high pressures with large pressure drop use may be made of the enthalpy-drop method directly, with sufficient accuracy.

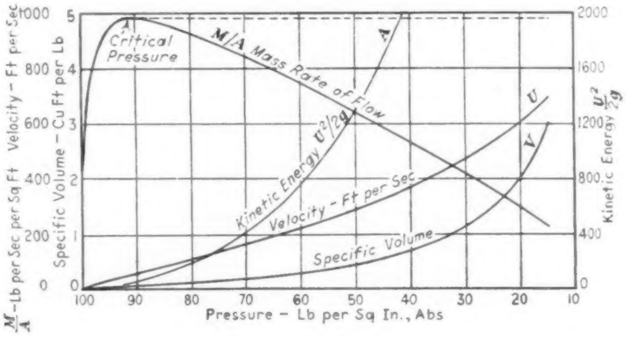


FIG. 9 NOZZLE CHARACTERISTICS FOR FLOW OF SATURATED LIQUID WATER

(Initial pressure 100 lb per sq in.)

Summarizing, for the reversible adiabatic process with saturated or compressed liquid water the value of the adiabatic enthalpy drop, $(H_1 - H_2)_s$ becomes

[3] "Principles of Engineering Thermodynamics," by Paul J. Kiefer and Milton C. Stuart, John Wiley & Sons, Inc., New York, N. Y., 1930, p. 182.

[4] "Thermal Properties of Compressed Liquid Water," by J. H. Keenan, MECHANICAL ENGINEERING, vol. 53, no. 2, February, 1931, pp. 127–131.

[5] "Thermodynamic Properties of Compressed Liquid Water," by C. Harold Berry, MECHANICAL ENGINEERING, vol. 57, no. 10, October, 1935, pp. 618–620.

$$\int_2^1 VdP_s = (P_1 - P_f)V_f + (P_f - P_2)(V_f + V_2)_s/2$$

where P_f is the saturation pressure corresponding to the liquid temperature, V_f the saturated-liquid specific volume corresponding to P_f or to liquid temperature, and V_2 the specific volume of the fluid after constant-entropy expansion to P_2 from P_f. If P_2 is equal to or greater than P_f the second term of the expression is omitted. All values of liquid properties required to perform the calculations may be obtained from the standard tables of properties of saturated liquid.

CHARACTERISTICS OF SATURATED-LIQUID FLOW

A detailed illustration of the method of computing ideal nozzle flow for saturated liquid is given in Fig. 9, which depicts nozzle characteristics for flow of saturated liquid water from an initial pressure of 100 lb per sq in. absolute. Abscissas are pressures throughout the nozzle as flow progresses, or they may be considered as the exit pressures for an ideal nozzle. The specific-volume curve V is computed in the usual manner for a constant-entropy expansion. The increase in specific volume results from the vaporization of part of the liquid at the lower pressures.

The kinetic-energy curve $U^2/2g$ is obtained by integrating the area of the specific-volume curve from the initial pressure.

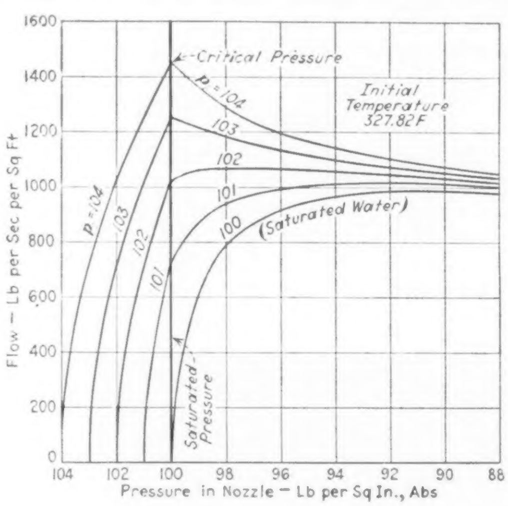


FIG. 10 NOZZLE CHARACTERISTICS FOR FLOW OF COMPRESSED LIQUID WATER, SHOWING THAT CRITICAL PRESSURE IS THE SATURATION PRESSURE

This is in accordance with the fundamental relation already stated

$$U^2/2g = J(H_1 - H_2)s = \int_2^1 VdP$$

The integration is obtained by arithmetical summation. The velocity curve U is obtained directly from the kinetic-energy curve. The mass rate of flow M/A is computed from the continuity-of-flow equation $M/A = U/V$. It should be noted that although M/A varies throughout the nozzle, actually the value of M lb per sec must be the same throughout the nozzle; therefore, the area A is the actual variable in the term M/A. The reciprocal of the M/A curve would be the curve of ideal nozzle areas. The point of maximum value of M/A (which is the point of minimum or throat area) establishes the critical or throat pressure. The high value of this critical pressure of 91 lb per sq in. compared with 57 lb per sq in. for saturated steam for the same initial pressure, may be said to be the most characteristic feature of the nozzle flow of saturated liquids. This critical pressure for saturated liquids has been computed for all pressures and is presented in Fig. 11. This will be referred to again.

CHARACTERISTICS OF COMPRESSED-LIQUID FLOW

The characteristics of nozzle flow of compressed liquids will now be investigated. An important phenomenon regarding critical pressure for this condition may be at once noted. This is, that the nozzle critical pressure for compressed-liquid flow is the saturation pressure corresponding to the initial liquid temperature. This fact is developed and illustrated in Fig. 10. The lower curve for $P_1 = 100$ is a portion of the flow curve for saturated liquid water, taken from Fig. 9 showing a critical pressure of 93 lb per sq in. for saturated liquid with an initial

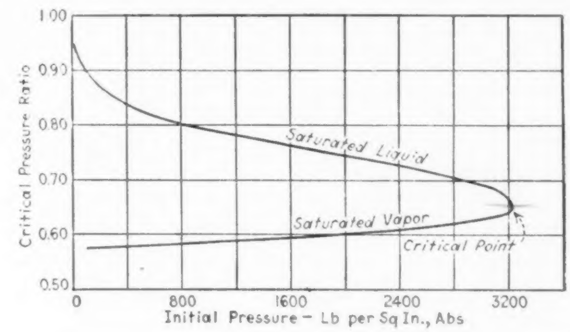


FIG. 11 CRITICAL-PRESSURE RATIOS FOR FLOW OF SATURATED STEAM AND SATURATED LIQUID WATER COVERING PRESSURES TO THE CRITICAL POINT

pressure of 100 lb per sq in. and the saturation temperature of 327.84 F. The critical pressure to be expected with compressed liquid supplied to the nozzle is investigated by plotting flow curves for initial pressures of 101, 102, etc., lb per sq in. all at the same temperature of 327.84 F, the saturation temperature corresponding to 100 lb per sq in. For a quite small amount of superpressure above the saturation pressure the critical pressure becomes the saturation pressure. In fact, this correspondence of critical pressure with saturation pressure is reached for a superpressure of 3 lb per sq in., which is equivalent to a subcooling of only 2 F (saturation temperature of 103 lb per sq in. is 330 F). This effect greatly simplifies the calculation of flow with compressed liquids. Flow of compressed liquid proceeds in the convergent portion of a nozzle exactly as a nonexpansible liquid from the entrance pressure to a critical pressure which is the saturation pressure corresponding to the initial temperature. In the divergent portion flow is accompanied by expansion of the saturated liquid, with partial vaporization and increase in specific volume. The mass rate of flow, however, is limited by the throat area and by the pressure drop from the upstream pressure to the saturation pressure. The energy released for flow is therefore $V_f\ (P_1 - P_f)$; provided P_2 is less than P_f. If P_2 is greater than P_f, the flow becomes the ordinary hydraulic problem with kinetic energy equal to $V\ (P_1 - P_2)$. Computations have been made of the saturated-liquid critical pressures, and corresponding critical-pressure ratios for pressures over the entire range to the critical point of steam, 3226 lb per sq in. These critical-pressure ratios are plotted in Fig. 11, together with the critical-pressure ratios for saturated steam. This curve is of interest in showing the high critical-pressure ratios for saturated liquid water, especially at low pressures, and the manner in which the curves for saturated vapor and saturated liquid meet at the

critical point. It is recalled that the chief significance of the critical-pressure phenomenon is its rôle in limiting flow through nozzles or rounded-entrance orifices for discharge pressures which are below the critical pressure.

Computations have been made of rates of nozzle flow of saturated liquid water over the range of pressures to the critical point. These are plotted in Fig. 12, together with the rates of flow of saturated steam. Here also the manner in which the curves join at the critical point may be noted. As a matter of interest, the steam flow computed from the

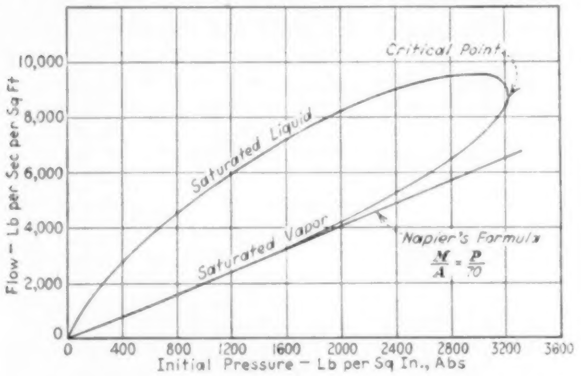


FIG. 12 RATES OF FLOW THROUGH NOZZLES FOR SATURATED STEAM AND SATURATED LIQUID WATER OVER A PRESSURE RANGE TO THE CRITICAL POINT OF STEAM

classical Napier formula $M = PA/70$ has been shown, with agreement, to a pressure of 1600 lb per sq in. The characteristic feature of saturated-liquid-water flow is its small amount compared with the flow of water at ordinary temperatures. At all pressures, except extremely low ones, the rate of flow of water at a temperature of 70 F is from four to seven times as great as the rate of flow of saturated water from corresponding

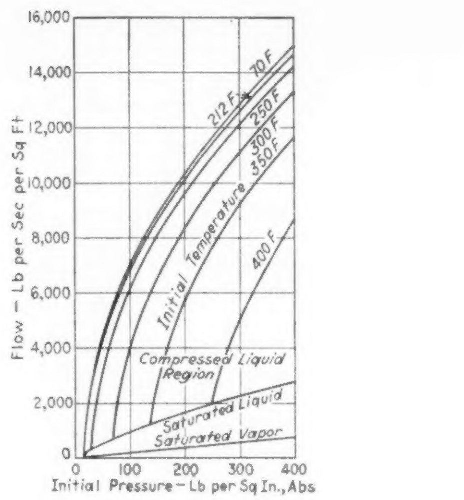


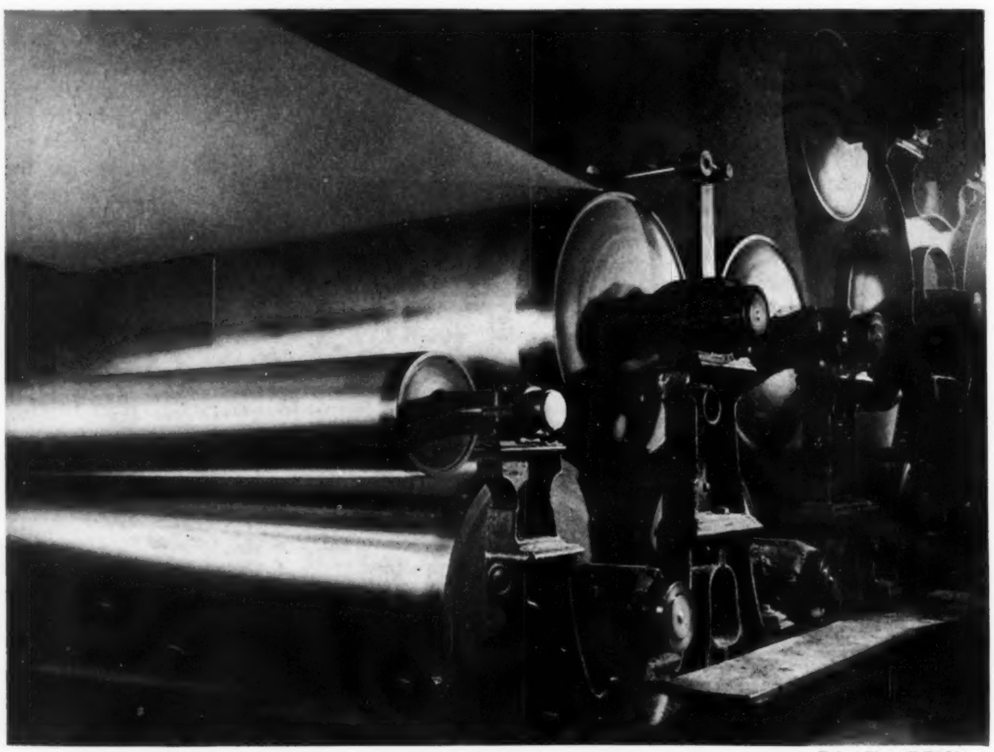
FIG. 13 RATES OF FLOW THROUGH NOZZLES FOR SATURATED AND COMPRESSED LIQUID WATER

pressures. This does not imply that higher velocities are not obtained in nozzles with saturated liquid.

In Fig. 13 are plotted the rates of flow of compressed liquid water covering pressures up to 400 lb per sq in. and the various temperatures of the compressed (subsaturated) liquid from saturation temperatures to a low temperature of 70 F. The effect of temperature on flow of compressed liquid is shown vividly by this group of curves.

ACKNOWLEDGMENT

Certain features of the flow of saturated and compressed liquids covered in this paper are treated in the paper "Discharge Capacity of Traps" by Kittredge and Dougherty, *Combustion*, September, 1934, page 14.



Robert Yarnall Richie

Photoelastic Studies in

STRESS CONCENTRATION

Fillets, Holes, and Grooves in Tension, Compression, and Bending

By MAX M. FROCHT

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THE SIGNIFICANCE of stress concentrations in the domain of strength of materials, especially where fatigue is present, is definitely established. This paper concerns itself with factors of stress concentration in a variety of practical cases and results are presented in a form which, it is hoped, will be of value to engineers and designers. Factors of stress concentration are given for holes, grooves, and fillets between fields of pure tension or compression, for grooves and fillets between fields of pure bending, and for deep and shallow grooves and fillets in tension, compression, and bending.

The results show that deep grooves and fillets increase materially the factor of stress concentration when r/d (see Fig. 4 for notation) is small, i.e., less than 0.2. This increase is more pronounced in tension than in bending. Shallow fillets and grooves in general reduce the factors of stress concentration. For large values of r/d (0.6 or more), however, the reduction does not set in until the discontinuity is quite shallow, so that the factor of stress concentration for half a fillet or groove is essentially the same as that for a full fillet or groove.

EXPERIMENTAL WORK

The researches reported in this paper were conducted in the Photoelastic Laboratory of the Department of Mechanics at the Carnegie Institute of Technology and cover a period of more than two years. The models used in all the tests were of Bakelite BT-61-893. The fringe method[1] was used throughout the work. The quality of the material, combined with careful selection and machining, made it possible to dispense with annealing in all but a few cases.

All models were cut and finished on a milling machine using end mills ranging in size from $^1/_8$ to $^3/_4$ in. in diameter. The factors of stress concentration were determined from several different loads, never less than two, and frequently more. In practically all cases of fillets these factors were determined by two methods—the photographic, and the semiphotographic—which are discussed toward the end of this paper. In cases of discrepancies tests were repeated until good agreement between the two methods was established.

PROGRESS IN THE DETERMINATION OF BOUNDARY STRESSES

The photoelastic method which in two-dimensional stress systems gives the difference of the principal stresses at all points of the stressed body, becomes especially significant at free-boundaries. At such boundaries there is only one principal stress in a direction tangent to the boundary. Theoretically, at least, the photoelastic method becomes ideal for the study of free-boundary stresses. These stresses are important for at least two reasons: First, they give the major stresses from which stress-concentration factors can be computed; second, the boundary stresses frequently form the starting point in the determination of the complete system of principal stresses.

FIG. 1 FILLETS IN COMPRESSION

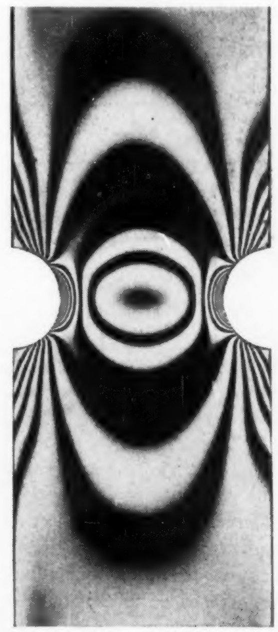


FIG. 2 SEMICIRCULAR GROOVES IN TENSION

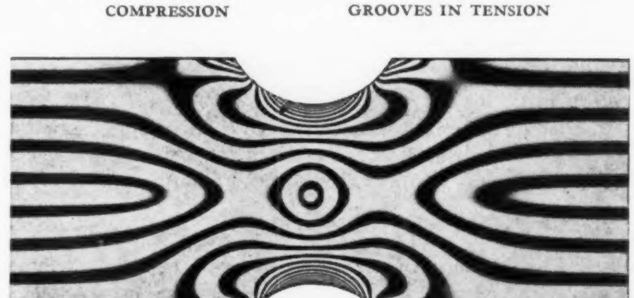


FIG. 3 SHALLOW GROOVES IN PURE BENDING

In the application of the method, however, difficulties are encountered which obscure the position of the true boundary and thereby interfere with the determination of the actual boundary stresses. Boundary vagueness has been noted by

[1] "Recent Advances in Photoelasticity," by Max M. Frocht, Trans. A.S.M.E., vol. 53, 1931, paper APM-53-11, pp. 135–153.

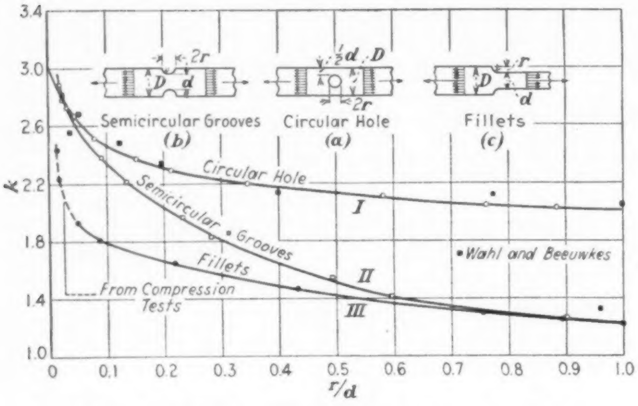


FIG. 4 INVARIANT CASES IN TENSION OR COMPRESSION

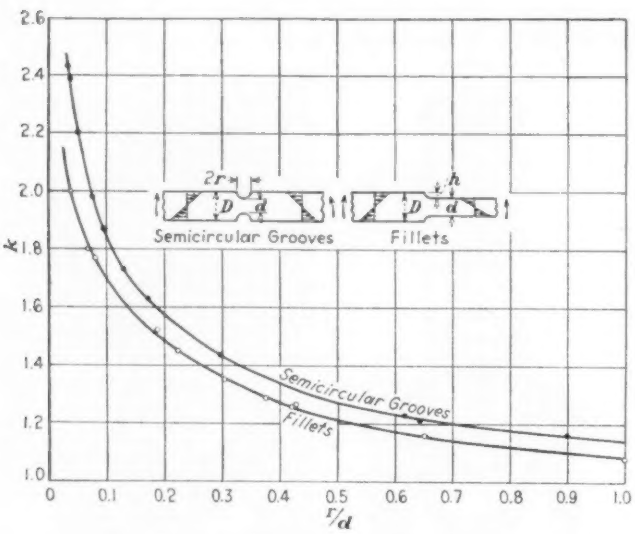


FIG. 5 INVARIANT CASES IN PURE BENDING

many investigators.[2] However, recent improvements in the photoelastic technique, a discussion of which must be omitted on account of limitations of space, make it possible to obtain stress patterns in which the boundaries and boundary stresses are clearly visible. It is believed that Figs. 1, 2, and 3 show such stress patterns. Stress patterns of such quality enable the direct determination of factors of stress concentration with a high degree of accuracy.

FACTORS OF STRESS CONCENTRATION AND INVARIANT CASES OF STRESS CONCENTRATION

The factor of stress concentration in cases of pure tension or compression is defined as the ratio of the maximum stress to the average stress in the section through the discontinuity, or

$$K = s_m/s$$

where K is the factor of stress concentration; s_m the maximum stress in the section; and s the average stress in the section computed by the expression, $s = P/A$, in which P is the axial load and A the cross-sectional area of the minimum section.

In the cases of bending the factor of stress concentration will be defined as the ratio of maximum stress to the stresses computed by the elementary flexure formula

$$K = s_m/(Mc/I)$$

in which M, c, and I denote, respectively, the usual bending moment, distance from the neutral axis, and moment of inertia.

The special cases in which

$$D = 2r + d$$

with notation as shown in Fig. 4, and in which the stress distribution is that of pure tension, compression, or bending will be referred to as *invariant* cases. These are singled out because of the relative simplicity of the end conditions, and because the factors of stress concentration in such cases can be readily expressed as functions of r/d. There are at least six invariant cases comprising circular holes, semicircular grooves, and fillets in tension, compression, and bending. Other cases will be referred to as nonvariant cases.

Curves I, II, and III in Fig. 4 give the factors of stress concentration for the three invariant cases in tension or compression. Curves shown in Fig. 5 give similar factors for two cases in pure bending, the latter being defined as regions of constant bending moment and linear distribution of the longitudinal stresses.

The results shown in curves I and II in Fig. 4 are in good

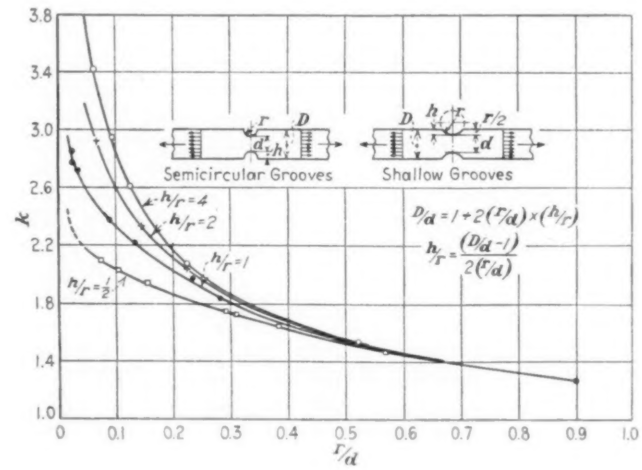


FIG. 6 DEEP AND SHALLOW GROOVES IN TENSION OR COMPRESSION

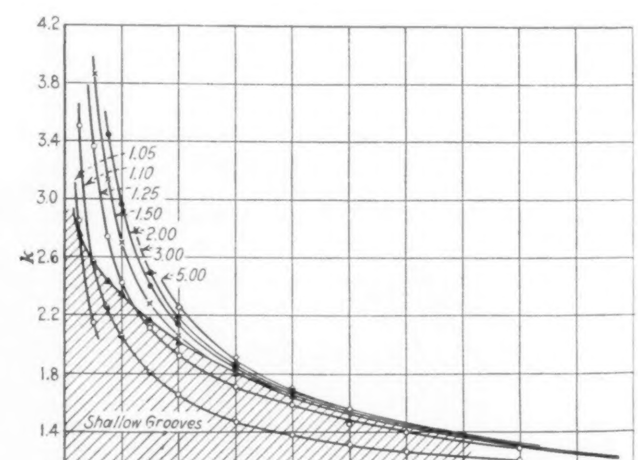


FIG. 7 DEEP AND SHALLOW GROOVES IN TENSION OR COMPRESSION

[2] "Stress Concentration Produced by Holes and Notches," by A. M. Wahl and R. Beeuwkes, Jr., Trans. A.S.M.E., vol. 56, 1934, paper APM-56-11, pp. 617–625.

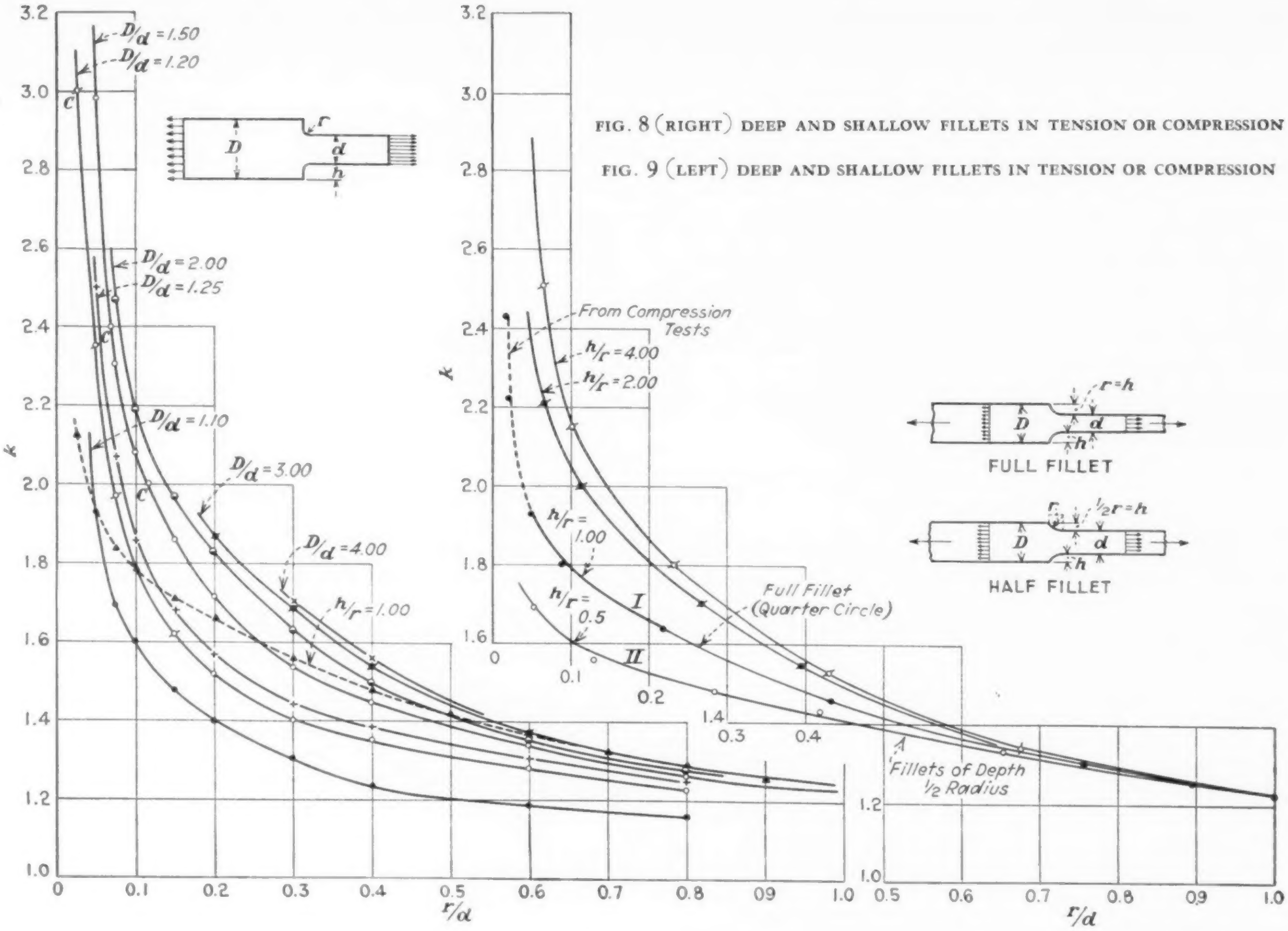


FIG. 8 (RIGHT) DEEP AND SHALLOW FILLETS IN TENSION OR COMPRESSION

FIG. 9 (LEFT) DEEP AND SHALLOW FILLETS IN TENSION OR COMPRESSION

agreement with those of Howland,[3] and those of Wahl and Beeuwkes.[2] The latter fall slightly above ours, but that is probably due to their method of extrapolation. To our knowledge these cases are the only strictly comparable investigations bearing on this subject.

DEEP AND SHALLOW GROOVES AND FILLETS IN TENSION, COMPRESSION, AND BENDING

By deep and shallow grooves or fillets we mean grooves or fillets in which h/r is, respectively, greater or smaller than unity, Fig. 6. In deep grooves or fillets the factors of stress concentration are greater than the factors in the corresponding invariant cases. This increase is especially noticeable at values of r/d less than 0.2. This increase is also more pronounced in tension than in bending and is also greater for grooves than for fillets. In shallow grooves or fillets the factors of stress concentration are smaller than the factors in the corresponding invariant cases.

Four cases are considered: Grooves in tension or compression and bending; fillets in tension or compression and bending.

Fig. 6 shows four curves giving the factors of stress concentration k as a function of r/d for h/r equal to $^1/_2$, 1, 2, and 4 for grooves in tension or compression, in which k is the photostatically determined value of the theoretical factor K. These curves will be referred to as *fundamental* curves. From the fundamental curves the set shown in Fig. 7 is derived. It is a simple matter to derive many additional curves of the types shown. It is also possible to express K as a function of h/r which is at times useful. In transforming the fundamental curves into functions of h/r or D/d, we make use of the expressions

$$D/d = 1 + 2(r/d)(h/r)$$

and

$$h/r = (D/d - 1)/2(r/d)$$

Figs. 6 to 13, inclusive, give the fundamental and derived curves for groove and fillets in tension and for grooves and fillets in bending.

Attention is again directed to the marked increase in the values of k due to increases in D/d or h/r for small values of r/d. For large values of r/d the curves are fairly flat for both deep grooves and fillets. Tests made in those regions of r/d are, therefore, misleading. The curves in Figs. 8 and 9 for fillets in tension show that for r/d equal 0.1 or less, k becomes extremely sensitive to small variations in D/d. Thus for $r/d = 0.05$, k jumps from 1.925 to 2.82, as D/d goes from 1.1 to 1.4 with corresponding changes in h/r from 1 to 4. This is equivalent to saying that in a model one inch wide a shoulder of $^1/_4$ in. will increase the factor of stress concentration by 47.5 per cent over the corresponding invariant case if a fillet of 0.05 in. radius is used.[4]

It is also important to observe that in shallow grooves and fillets in which r/d is large the factors of stress concentration

[3] "On the Stresses in the Neighborhood of a Circular Hole Under Tension," by R. C. J. Howland. Phil. Trans., Royal Society of London, vol. 229A, 1929, p. 49.

[4] In this respect our results disagree with those of Dr. Weibel who gives the same curve for $D/d = 1.5$ and $D/d = 3$. See "Studies in Photoelastic Stress Determination," by E. E. Weibel, Trans. A.S.M.E., vol. 56, 1934, paper APM-56-13, pp. 637–658.

remain essentially constant for a considerable drop in the value of h/r. Thus for r/d as high as 0.6, k for fillets in tension is 1.345 for a half fillet and 1.36 for a full fillet. For $r/d = 0.8$ the difference is even less; k being 1.28 for a half fillet and 1.285 for a full fillet.

METHODS FOR THE DETERMINATION OF FACTORS OF STRESS CONCENTRATION

In a model free from initial stresses, in which the fringes are due to the applied loads only, the factor of stress concentration can be determined completely from a single stress pattern of known fringe orders. It is not necessary to know the loads, the fringe value, or the dimensions of the model. This is at least true for fillets in tension or compression.

If the fringe orders corresponding to the average and maximum stresses be denoted by N and N_m, respectively, then the corresponding stresses s and s_m are given by

$$s = 2FN$$

and

$$s_m = 2FN_m$$

in which F denotes the fringe value of the model defined as the change in the shear stress necessary, at a particular wave length of the light, to change the fringe order at any point of the model by one. Hence

$$K = s_m/s = 2FN_m/2FN = N_m/N$$

The factor of stress concentration can thus be completely determined from the two fringe orders N and N_m, both of which can be directly read from the stress patterns.

THE SELF-CORRECTING OR BRIGHT-SHANK METHOD

In practice it is well-nigh impossible to obtain models free from machining stresses. Denoting the initial boundary stress in the fringes due to machining by n_0, the observed stress at the discontinuity by n_m, and the computed average stress by n', where $n' = P/2AF$, we get for the factor of stress concentration

$$K = (n_m \pm n_0)/n'$$

the plus sign applying to a tension test and the minus sign to compression tests, since the machining stresses are compressive in character.

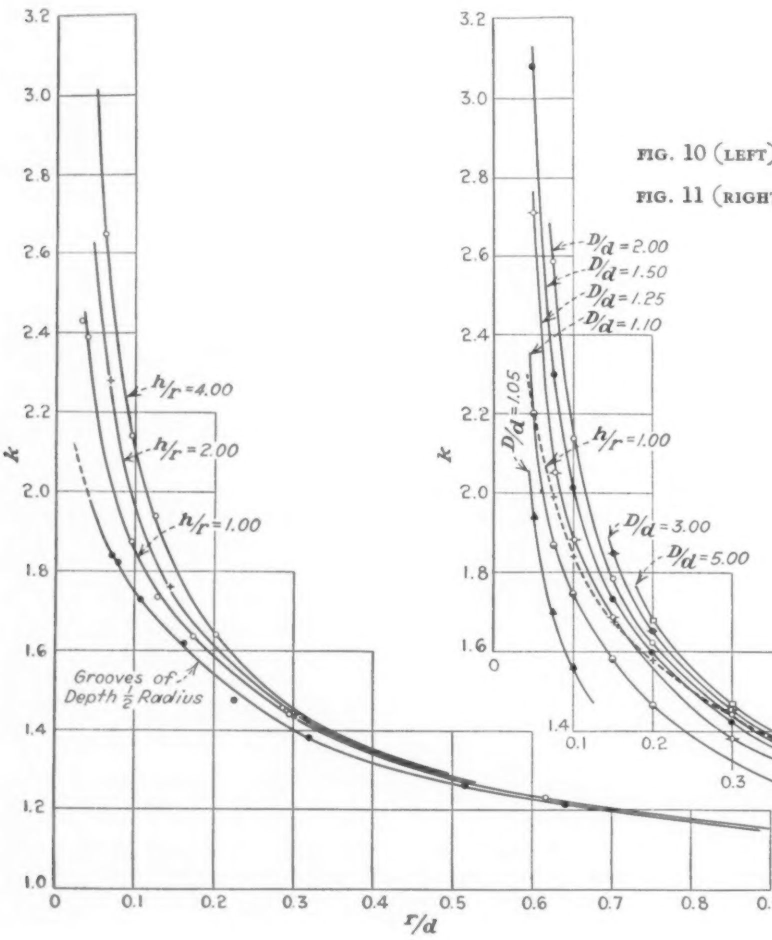
The approximation of K which is obtained by neglecting the edge stress n_0 and taking fringe orders from a stress pattern when the shank is uniformly bright we denote by k. Thus

$$k = n_m/n$$

in which n is the fringe order in the shank to the nearest half fringe when the background is dark, and n_m is the observed fringe order at the discontinuity. It can be shown that k is the quickest and most reliable method to figure stress-concentration factors for fillets in tension, or compression. This method automatically corrects for initial boundary stresses due to machining.

The author has shown[5] that if n_m be kept close to ten fringes

[5] The theory of this method is discussed in the author's paper: "Some New Aspects of Stress Concentration," presented before the American Association for the Advancement of Science Convention, held in Pittsburgh, in December, 1934.



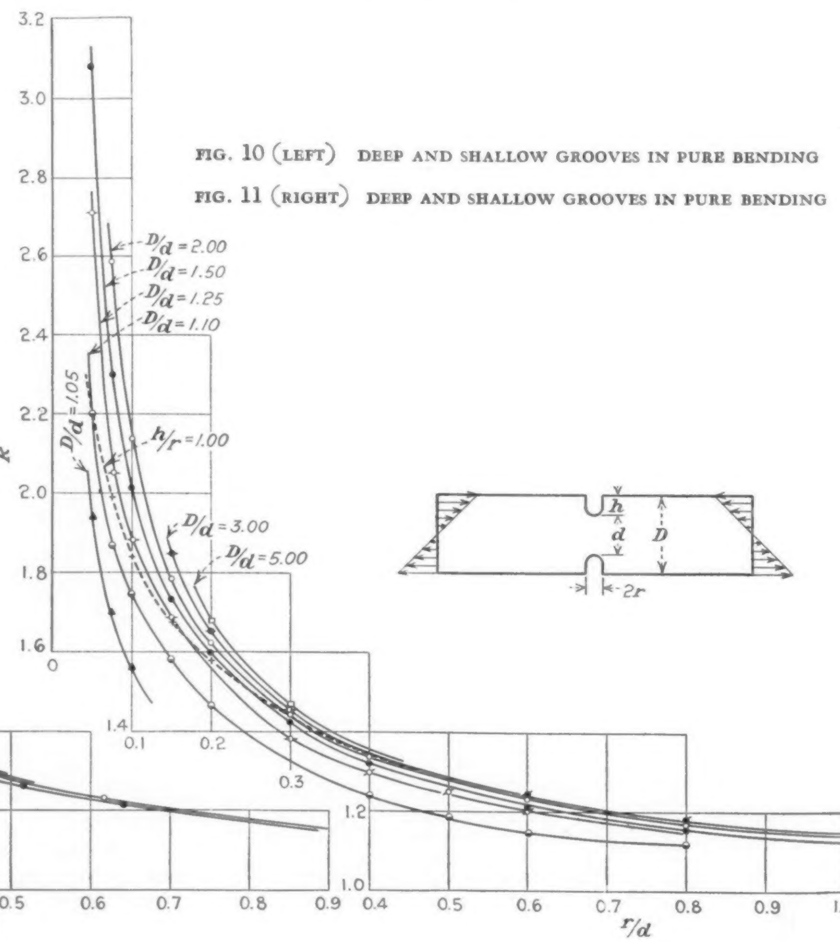


FIG. 10 (LEFT) DEEP AND SHALLOW GROOVES IN PURE BENDING

FIG. 11 (RIGHT) DEEP AND SHALLOW GROOVES IN PURE BENDING

and n_0 does not exceed half a fringe, the maximum errors introduced by using k instead of K are within ± 2.5 per cent. This method is referred to as the "photographic method" in the introduction to the paper.

Another approximation to K can be obtained from the formula

$$k_1 = n_m/n'$$

in which n' is the computed average stress. The method which is represented by k_1 is referred to as the "semiphotographic" method.

Experiments show that stress concentrations depend not only on the shape and dimensions of the discontinuity, such as fillets, holes, or grooves, but also on the distribution of the stresses on both sides of the discontinuity. It has been found that any change in the dimensions of the body or in the method of supporting it which alters the stress distribution in one or both sides of the discontinuity affects the factor of stress concentration.

In the investigations reported in this paper the loads were applied at a sufficient distance from the discontinuity to assure pure tension, compression, or bending.

ACKNOWLEDGMENTS

The author takes this occasion to express his appreciation and acknowledgments to the following: The administration of The Carnegie Institute of Technology, especially Dr. Webster N. Jones, director of the College of Engineering, and Prof. N. C. Riggs, head of the Department of Mechanics, for their interest in and support of this work; to R. E. Peterson, of the Westinghouse Electric and Manufacturing Company, with whom the author has had a number of profitable conferences; to Prof. S. Timoshenko for a useful suggestion in connection with deep grooves and fillets; to the federal government for furnishing assistance in some of the photographic aspects of the work; and to M. M. Leven, assistant in the photoelastic laboratory, for his cooperation.

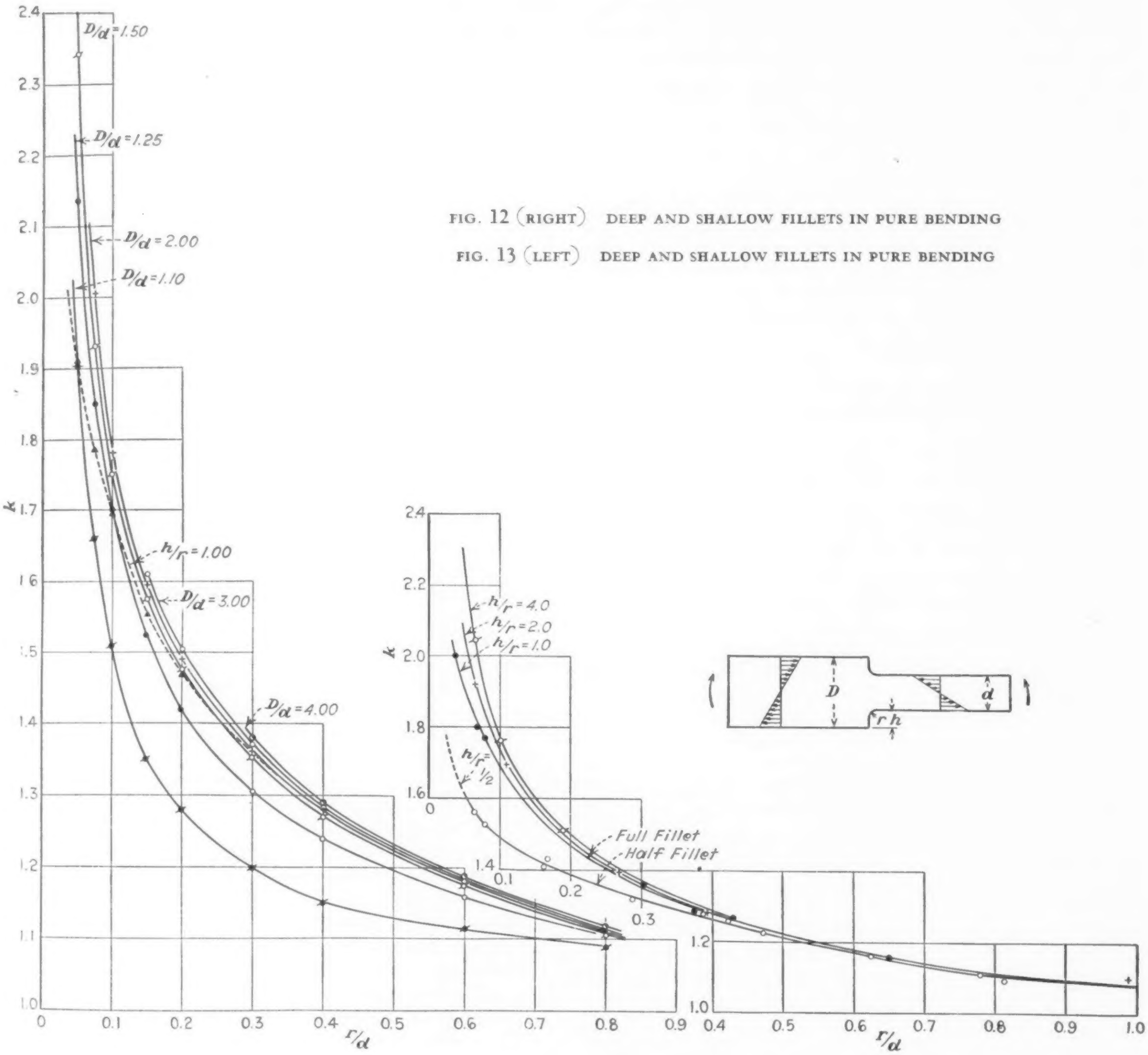


FIG. 12 (RIGHT) DEEP AND SHALLOW FILLETS IN PURE BENDING

FIG. 13 (LEFT) DEEP AND SHALLOW FILLETS IN PURE BENDING

BOSE'S QUANTUM STATISTICS APPLIED *to* PLANCK'S FORMULA *for* THERMAL RADIATION

By VLADIMIR KARAPETOFF

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SUMMARY

THIS ARTICLE[1] is a detailed review of the mathematical methods employed and not an original contribution to the subject. A box filled with thermal radiation has a small hole through which a negligible portion of the total radiant energy is allowed to fall on a prism which resolves it into a spectrum. The intensity distribution is measured with a suitable radiometer and plotted against wave lengths as abscissas. Planck's familiar formula agrees well with these curves. The purpose of the article is to deduce Planck's formula using Bose's statistical method. Expressions are given for the energy and the momentum of a photon and then the number of degrees of freedom of electromagnetic radiation in an enclosure is deduced, leading to the Rayleigh-Jeans formula. The use of a representative momentum space is explained, with equal cells of finite magnitude, in accordance with the quantum theory, and the size of a cell is determined from the preceding considerations.

A detailed treatment is then given of the general properties of distribution of a given number of indistinguishable particles in a given number of distinguishable cells, and formulas are deduced for the number of arrangements in two cases: (*a*) When the number of particles in each cell is arbitrary, and (*b*) when the partial number of cells, each with a given number of particles, is specified. The formulas are extended to the case of an unlimited number of sets of cells, to correspond to the sets of vectors of momenta in the representative space, and it is shown how to determine the maxima of the possible numbers of arrangements, using Stirling's theorem. To complete the theoretical data, entropy is introduced as a quantity proportional to the logarithm of the thermodynamic probability of the macroscopic state. An expression for the entropy of a perfect gas is given to determine the value of the coefficient of proportionality between the entropy and the logarithm of the probability of the state. Bose introduces the same constant in his expression for the entropy of radiation, although his method of computing the probability is quite different.

The data and the methods so far given are now assembled together into a treatment leading to Planck's formula. For this purpose, the probability formula is used with the number of particles per cell unlimited. The maximum of the number of arrangements gives the most probable state and leads to a definite relationship between the number of cells and the number of photons in each layer. Multiplying this number of photons by the quantum expression of the energy in each, and introducing the number of cells derived from the computed number of degrees of freedom per unit volume of the enclosure, leads to Planck's formula. It is then shown that the same result is obtained by starting with the formula for the number of arrangements when the numbers of cells of each kind are prescribed.

[1] Another article dealing with statistical theory was presented by Professor Karapetoff in the April, May, and June, 1933, issues of MECHANICAL ENGINEERING under the title "The Fermi-Dirac Statistical Theory of Gas Degeneration With Some Applications to Electronic Phenomena in Metals."

NOTATION

No particular units are indicated or used in the article, the formulas and the deductions being true in any consistent system of units.

A = amplitude of function ψ in Eq. [18]
a = linear dimensions of a cubic box in which thermal radiation takes place
B = undetermined factor in Eq. [59] whose value later is found to be that given by Eq. [64]
C = number of degrees of freedom of radiation, per unit volume, within given limits of frequency; also, in a mathematical sense, a number of cells
C' = $2C''$, same as C'', with the possibility of two equal numbers of photons polarized in mutually perpendicular planes
C'' = number of sets of integers m, n, and p, which satisfy Eq. [19] for a given value of ν
c = velocity of light
c_v = specific heat of a perfect gas at a constant volume
D = number of permutations
E = energy per photon
E_t = total energy of the radiation, including all wave lengths
e_λ = monochromatic emissive power
$\exp w$ = ϵ^w, where ϵ is the base of Naperian logarithms
f_1, f_2 = numbers of favorable events
$f(n)$ = a symbol for $\log n!$
G = electric intensity or potential gradient
H = magnetic intensity or magnetizing force
h = Planck's constant, quantum of action
i = as a subscript means the general ith term
j = square root of minus one
K = volume of a cubic enclosure of linear dimensions a
k = R/N_0, gas constant per molecule (Boltzmann's constant)
L = volume of a shell between two concentric spherical surfaces in the representative momentum space
m = mass of a particle
m, n, p = positive integers in Eq. [18]
N = number of particles, or more specifically the number of photons per layer of cells in the momentum space
N_0 = number of molecules in a gram molecule of a perfect gas (Avogadro's number)

n = a positive integer
P = gas pressure
p = momentum of a particle or of a photon
p_1, p_2 = probabilities of individual events
p_{12} = probability of events 1 and 2 occurring simultaneously
p_i = probability of state of the ith portion of a quantity of gas
p_t = total probability of a compound event
Q = total heat communicated
q = an undetermined multiplier, later found to be equal to $1/kT$; see Eqs. [45], [59], and [91]
R = gas constant per gram molecule; see Eq. [4]
r = a serial notation meaning, 0, 1, 2, 3, etc., and used specifically to indicate taking a sum or a product within a layer in the momentum space
S = total entropy
s_i = partial entropy
T = absolute temperature of radiation
t = time
t as a subscript means "total," indicating a product taken over all the layers in the momentum space, or over any other partial probabilities
t_1, t_2 = total numbers of occurrences in two independent series
U_t = denominator of Eq. [48]
u = velocity of a particle
V = number of arrangements when all the Z_i's are given; also the corresponding thermodynamic probability per layer in the momentum space
v = specific volume of gas, per gram molecule
W = number of arrangements of particles in cells, or thermodynamic probability per layer in the momentum space
x, y, z = space coordinates
Z_i = number of cells having i particles or photons each
θ = that factor of H or G which is a function of space coordinates only, and not of time
κ = dielectric constant or permittivity of a medium
λ = wave length
μ = magnetic permeability of a medium
ν = frequency of monochromatic radiation
Π = product
ρ = a very large number defined by Eq. [21] and used as the radius in Fig. 3.
Σ = sum
ϕ = a symbol for either H or G
ψ_ν = density of energy of monochromatic radiation as a function of frequency ν per unit range of ν
ψ_λ = density of energy of monochromatic radiation as a function of wave length λ, per unit range of λ.

INTRODUCTION

During the closing years of the nineteenth century Max Planck was investigating the distribution of radiant energy in the spectrum of black-body radiation and was trying in vain to deduce, on the basis of classical physics, a formula which would reasonably agree with the measured distribution. He then proposed, in 1900, a revolutionary theory of quanta according to which small amounts of radiant energy do not vary in magnitude continuously, but in very small finite steps (20, 13, 18).[2]

On the basis of this hypothesis, he succeeded in deducing a formula which, within a given range of wave lengths and for a given temperature, gives the volume density of radiant energy in an enclosure (black-body). Planck's formula has been carefully checked since, with many available experimental data, and is recognized as being of a considerable degree of accuracy, although Planck himself referred to it as being only an interpolation formula found by lucky guesswork. Various theoretical deductions of this formula were not considered as altogether rigid and convincing until the Hindu physicist Bose (2) proposed a fundamentally different method of statistical analysis of quanta, and using this method (perhaps by another lucky guess) deduced Planck's formula in a rather natural, compelling way. This success has established Bose's statistics as applying to quanta of radiation in general.

The purpose of this article is to explain Bose's method of computing probabilities of state of a large aggregate of particles and to deduce Planck's formula as a result. While an exposition of Bose's theory may be found in several articles and books (1, 4, 9, 12, 15, 17) the theory is usually given in a somewhat fragmentary way, and the reader is assumed to guess at reasons for several statements and to take on faith a number of mathematical laws and transformations, or to look them up elsewhere. In this article an attempt is made to explain the essential points of all the necessary physical assumptions and mathematical expressions in the body of the text, without referring the reader to outside sources. The list of references appended at the end of the article is mainly indicative of the sources studied by the author himself in the preparation of the article.

In arranging the available material, the first thought was to write a consecutive narrative, digressing here and there to explain a reason for this or that statement or formula. It was felt, however, that such a method would conceal the comparatively simple reasoning on which Bose's method is based behind a maze of mathematical detail. The next procedure considered was that of relegating such details to a number of appendixes. However, this would have made the size of the appendixes larger than that of the article itself and would split the reader's attention.

Finally the author decided on a somewhat unusual method of presentation consisting in writing a number of fairly independent introductory physical and mathematical sections followed by an explanation of Bose's statistical method based on these sections. The introductory parts treat of various physical considerations and mathematical deductions, most of which are not specifically parts of Bose's theory but are needed in order to understand this theory.

The reader need not study all the introductory sections, but only those which have an element of novelty for him. The results obtained in these sections are simply referred to in the last section of the text, thus making the main narrative more connected and concise. In other words, when the reader studies Bose's ideas and reasoning proper, he is already familiar with the "previous art" and need not be distracted by somewhat lengthy mathematical deductions not original with Bose.

1 EXPERIMENTAL CURVES OF BLACK-BODY RADIATION

The fundamental phenomenon whose theory is the subject of this article is shown schematically in Fig. 1. A closed box B with a perfectly reflecting inner surface is maintained at a constant fairly high temperature T and is therefore filled with radiant energy in the form of electromagnetic waves. These waves are of the same general nature as visible light, only their frequencies, theoretically at least, range from zero to infinity. The waves are repeatedly reflected from the inner surface of the box, as shown diagrammatically by the broken line *abcde*,

[2] Numbers in parentheses refer to the Bibliography at the end of the paper.

and the whole radiation may be said to be in a state of dynamic equilibrium so long as the temperature remains constant.

A small opening H is provided in one of the walls and through it a negligible portion of the total radiation is allowed to escape for purposes of measurement. P is a prism through which the issuing beam is refracted and spread out into a spectrum. A rotatable radiometer R is placed in the path of any desired part of the spectrum, and in this manner the energy of a particular narrow band of frequencies (or wave lengths) measured. The results are usually represented as shown in Fig. 2.

In this figure values of wave length λ are plotted as abscissas

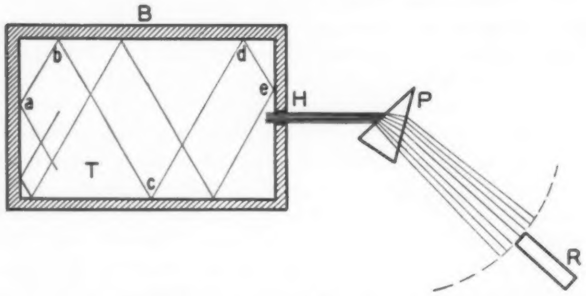


FIG. 1 THE PRINCIPLE OF MEASUREMENT OF THE SPECTRAL DISTRIBUTION OF ENERGY IN BLACK-BODY RADIATION

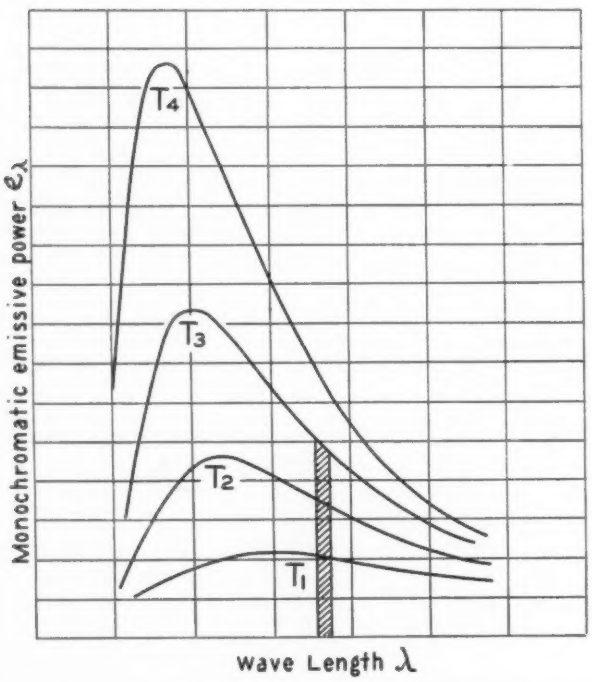


FIG. 2 DISTRIBUTION OF MONOCHROMATIC EMISSIVE POWER IN THE SPECTRUM OF BLACK-BODY RADIATION AT VARIOUS TEMPERATURES

against "monochromatic emissive power" e_λ as ordinates. The latter may be defined as the radiant energy emitted per unit area of the opening H (Fig. 1), per unit time, per unit wave length, at the wave length λ. In other words, at a temperature T the actual power measured by the radiometer within a small range of wave lengths $\Delta\lambda$ at λ is $e_\lambda\Delta\lambda$, and is represented by the cross-hatched strip in Fig. 2. Consequently, the total area between the curve T_3 and the axis of abscissas gives the rate at which the total radiant energy streams out of the small opening, per unit area and per unit time.

Each curve corresponds to a different temperature; as the temperature within the enclosure increases the maximum of monochromatic emissive power is shifted toward shorter wave lengths (Wien's displacement law). The experimental details of the arrangement are of no concern to us here, but we are interested in the following results:

(1) Temperature radiation consists of waves of different frequencies or wave lengths, forming a continuous band or spectrum.

(2) The total energy associated with a narrow range of frequencies can be accurately measured by a delicate instrument.

(3) At a given temperature T the character of the radiation and the energy distribution is the same, no matter what the size, shape, or material of the enclosure (black body) may be.

In the theory that follows we shall be concerned with the distribution of radiation within the enclosure and not with its spectrum on the outside. The foregoing experiment is described only to make the theoretical discussion more real and to show how a mathematically deduced expression for the density of energy within the enclosure may be verified by measuring its spectral distribution outside.

2 PLANCK'S RADIATION FORMULA

Max Planck has shown (18, 20) that any curve in Fig. 2 may be fairly accurately represented by the equation

$$\psi_\lambda\, d\lambda = 8\pi ch\lambda^{-5}d\lambda/[\exp(ch/\lambda kT) - 1] \qquad [1]$$

or by an equivalent equation

$$\psi_\nu d\nu = 8\pi h(\nu^3/c^3)d\nu/[\exp(h\nu/kT) - 1] \qquad [2]$$

In these expressions, the symbols have the following meaning: The density of energy of monochromatic radiation within the enclosure is denoted by ψ. Thus ψ_λ is the energy of radiation per unit volume at wave length λ for unit range of λ. This means that the actual density of energy for a band of wave lengths between λ and $\lambda + d\lambda$ is equal to $\psi_\lambda d\lambda$. Similarly, ψ_ν is the energy of radiation per unit volume of the enclosure at wave frequency ν for unit range of ν. In other words, the actual density of energy for a band of frequencies between ν and $\nu + d\nu$ is equal to $\psi_\nu d\nu$. The velocity of light in vacuo is denoted by c, and since waves of all frequencies are propagated at this velocity, we have

$$\lambda = c/\nu \text{ and } d\lambda = -cd\nu/\nu^2 \qquad [3]$$

Assuming Eq. [1] to be given and substituting for λ and $d\lambda$ on the right-hand side their values from Eqs. [3] will give the right-hand side of Eq. [2]. The factor by which $d\nu$ is multiplied being denoted by ψ_ν gives the left-hand side of Eq. [2]. Thus, the two equations being equivalent, it is sufficient to consider one of them. It is the object of this article to deduce Eq. [2] theoretically, using Bose's statistical method.

The curves in Fig. 2 give values of monochromatic emissive power e_λ whereas Eq. [1] gives the value of the density of energy of monochromatic radiation ψ_λ at a point within the enclosure. However, the two quantities are proportional to each other, that is, e_λ/ψ_λ = const, the constant being the same for any wave length. This follows from the consideration that the energy of radiation issuing per second through the opening H (Fig. 1) is a small fraction of the energy stored per cubic centimeter in the enclosure and is entirely determined by the latter energy and by the geometric considerations which do not depend upon the value of λ. Hence, by introducing a proper constant, e_λ may be substituted on the left-hand side of Eq. [1] in place of ψ_λ (16, 20).

The factor h which enters in Eqs. [1] and [2] is the so-called

Planck's action constant which at the present time is considered to be one of the fundamental physical constants, on a par with the velocity of light, electronic charge, etc. (18). Its value depends upon the units used and may be found among various tabulations of physical constants. Its dimensions are those of "action," that is, energy times time, or momentum times length. This may be checked from the expression $ch\lambda^{-5}$ in Eq. [1] whose dimensions must be those of energy divided by (length)^4.

The factor k, known as Boltzmann's constant (or the molecular gas constant), is also one of the fundamental physical constants. Its physical dimensions are those of energy per degree of temperature, as may be seen from the exponent in Eq. [1] whose dimensions must be those of a numeric. Perhaps the simplest way of explaining the meaning of k is to begin with the fundamental equation of thermodynamics of perfect gases, namely

$$Pv = RT \quad [4]$$

with which most readers are familiar. Here P is the gas pressure, v the volume per gram molecule of mass, and T the absolute temperature. The factor R is a universal constant referring to one gram molecule of gas. According to Avogadro's law, the number of molecules per gram molecule is the same for all substances, say N_0. By definition

$$k = R/N_0 \quad [5]$$

In other words, k is the familiar thermodynamic constant R per molecule of gas. Strangely enough, the same constant plays an important part in the phenomenon under consideration which has to do with quanta of radiation and not with particles of a material substance.

As previously mentioned, it is our problem to deduce Eq. [2] theoretically.

3 THE ENERGY AND MOMENTUM OF A QUANTUM OF RADIATION OR PHOTON

Modern atomic and electronic physics is based on a number of postulates, or working hypotheses, which are mainly justified by the fact that formulas and laws deduced on their basis agree satisfactorily with experimental results, and also because some observed phenomena can be conveniently described in terms of these postulates. Thus, to explain liberation of electrons from certain metals by impinging electromagnetic radiation (the photoelectric effect) or to explain production of X rays by electronic bombardment, it is almost necessary to assume that electromagnetic waves (including visible light) do not consist of continuous "physical rays," but are discrete "chunks" of limited length and energy. Such apparently indivisible units of radiations, or atoms of light, are called *photons*. A photon is characterized by a definite frequency ν and is propagated at the velocity of light c, irrespective of the frequency. The fundamental hypothesis in regard to photons is that the total amount of energy E associated with each is

$$E = \nu h \quad [6]$$

where h is Planck's constant already mentioned (5). The ordinary ponderable mass of a photon must be assumed equal to zero, for otherwise, in accordance with Einstein's restricted theory of relativity, this mass would become infinitely great at the velocity of light.

To deduce an expression for the momentum of a photon without introducing a mass equal to zero, we shall make use of two formulas, Eqs. [7] and [8], of the restricted theory of relativity. For their deduction the reader is referred to an elementary book or article on the subject (24), or else he may take them as postulates of relativity.

Consider a material particle moving at a velocity u smaller than that of light. The total energy of the particle is then

$$E = mc^2 \quad [7]$$

where m is not the mass which the particle has at rest, but a larger mass which is a function of u. Thus E is not a constant quantity, as may seem from a superficial inspection of the formula, but is a function of u. Furthermore, the momentum of the particle is

$$p = mu \quad [8]$$

where again m is the same function of u as in the expression for the total energy. Eliminating m between Eqs. [7] and [8] gives

$$p = Eu/c^2 \quad [9]$$

We shall now assume that Eq. [9] holds true in the limit when the velocity of the particle increases to c and its mass, when at rest, is assumed to approach zero. Putting $u = c$ and using the expression for E from Eq. [6] we obtain

$$p = \nu h/c \quad [10]$$

Eqs. [6] and [10] are used later in the deduction of Planck's formula [2].

4 ON THE NUMBER OF DEGREES OF FREEDOM OF ELECTROMAGNETIC RADIATION IN AN ENCLOSURE

When a certain amount of radiation within an enclosure, Fig. 1, is in a stationary state, theoretically, only waves of definite frequencies can exist, namely, those capable of forming standing waves. This means a definite relationship between the wave lengths and the dimensions of the enclosure. Of course, the usual wave lengths are so small compared to the dimensions of a practicable enclosure that this relationship simply means a possible number of distinguishable waves whose frequencies lie between any two chosen limits, say ν and $\nu + \Delta\nu$. This number of waves is also referred to as the number of degrees of freedom in the radiation within these limits of frequency. The deduction is based on the fundamental equation of propagation of electromagnetic radiation, and the principal steps in the deduction of this equation will be pointed out to refresh the reader's memory.

Consider a plane electromagnetic wave propagated along the positive X-axis. Let the electric intensity G be directed along the Y-axis and the magnetic intensity H along the Z-axis. Let the system of axes be right-handed. If the absolute dielectric constant of the medium is κ, the dielectric-flux density is κG and the corresponding density of the displacement current is $\kappa\,\partial G/\partial t$. The magnetomotive force created by this current per unit area perpendicular to G is $-\partial H/\partial x$, so that in the proper units

$$\kappa\,\partial G/\partial t = -\partial H/\partial x \quad [11]$$

In this equation H is expressed in such units that the magnetomotive force of a current i is also equal to i, and not to $4\pi i$. The magnetic-flux density is μH, where μ is the absolute permeability of the medium. The rate of change of the flux density with the time is $\mu\,\partial H/\partial t$. Hence, the equation of induced electromotive force is

$$\mu\,\partial H/\partial t = -\partial G/\partial x \quad [12]$$

Elimination of one of the variable field vectors from Eqs. [11] and [12] gives

$$\partial^2\phi/\partial t^2 = c^2\partial^2\phi/\partial x^2 \ldots\ldots\ldots\ldots [13]$$

where ϕ stands for either H or G, and the velocity of propagation is

$$c = \sqrt{1/\mu\kappa} \ldots\ldots\ldots\ldots [14]$$

In a more general case, when the wave is not plane, Eq. [13] becomes

$$\partial^2\phi/\partial t^2 = c^2(\partial^2\phi/\partial x^2 + \partial^2\phi/\partial y^2 + \partial^2\phi/\partial z^2) \ldots [15]$$

and ϕ is a vector function of the coordinates of the point under consideration.

If the wave is due to a harmonic oscillator of frequency ν, ϕ is a sine function of time, so that we may put (Ref. 16)

$$\phi = \theta(x, y, z)\exp(2\pi j\nu t) \ldots\ldots\ldots\ldots [16]$$

where $j = \sqrt{-1}$ and θ expresses the dependence of ϕ on the space coordinates alone. Substituting this value of ϕ in Eq. [15] and canceling out the exponential factor, we get

$$4\pi^2\nu^2\theta + c^2(\partial^2\theta/\partial x^2 + \partial^2\theta/\partial y^2 + \partial^2\theta/\partial z^2) = 0 \ldots [17]$$

Let the hollow space under consideration be a cube of linear dimensions a, with the inner surfaces perfectly reflecting. According to the electromagnetic theory of light, a perfectly reflecting surface must belong to a perfect conductor of electricity. Therefore, if ϕ stands for the electric intensity, θ must be equal to zero at any point on the walls, because a finite electric intensity would produce an infinite current in a perfect conductor. We therefore may try

$$\theta = A\sin(m\pi x/a)\sin(n\pi y/a)\sin(p\pi z/a) \ldots\ldots [18]$$

where m, n, and p are positive integers and A is a constant. This expression satisfies the condition that when $x = 0$ or $x = a$, $\theta = 0$; the same is true of y and z. Substituting expression [18] in Eq. [17], we obtain, after simplification

$$4a^2\nu^2/c^2 = (m^2 + n^2 + p^2) \ldots\ldots\ldots\ldots [19]$$

It remains to compute the number of sets of integer values of m, n, and p possible with values of frequencies which lie between 0 and ν.

To illustrate the method by means of a sketch, Fig. 3, we shall first solve the problem in two dimensions. Let an inequality of the form

$$m^2 + n^2 < \rho^2 \ldots\ldots\ldots\ldots [20]$$

be given where m and n are integers and ρ is a very large number. Let it be required to compute the number of possible sets of values of m and n which satisfy this inequality. In Fig. 3 a quadrant of radius ρ is drawn and the ruling corresponds to the integer values of m and n, equal to 1, 2, 3, etc. Every point of intersection on the ruling gives a set of possible values of m and n. Since by assumption ρ is a very large number, the grating must be imagined as being very fine.

The required number of combinations is thus equal to the number of points of intersection within the quadrant. But the area of each small square is equal to unity, so that the number of points sought is very nearly equal to the area of the quadrant. In other words, the possible number of combinations is equal to $\pi\rho^2/4$.

The method can be readily extended to three dimensions, giving at once the solution of Eq. [19]. Imagine the integers m, n, and p to be plotted along some three orthogonal axes of coordinates, so that certain discrete points in space, forming a unit-cube lattice, similar to the plane lattice in Fig. 3, give various possible combinations of the three integers. Let

$$\rho = 2a\nu/c \ldots\ldots\ldots\ldots [21]$$

An octant of a sphere of radius ρ with its center at the origin will contain all the representative points which will give values of ν between zero and ν. Since the representative points are spaced at unit distance, the volume of the octant, or the number of unit cubes, will give the number of representative points. The wave length of radiation is assumed to be very small compared with the dimensions of the enclosure, so that m, n, and p are very large integers and the unit cubes are exceedingly small compared to the volume of the sphere.

Thus C'', the number of representative points, or of sets of

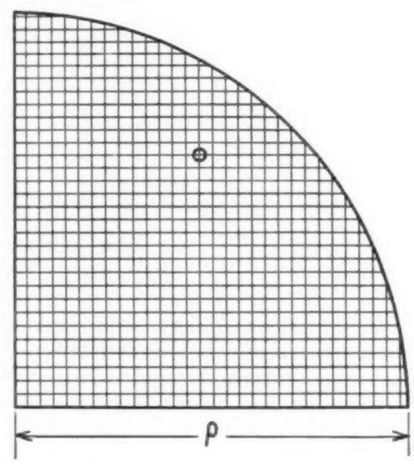


FIG. 3 COMBINATIONS OF POSITIVE INTEGERS POSSIBLE WITHIN A QUADRANT OF VERY LARGE RADIUS

values of m, n, and p in Eq. [19], is equal to the volume of the octant

$$C''(0,\nu) = 4\pi\rho^3/(3 \times 8) = 4\pi a^3\nu^3/(3c^3) \ldots\ldots [22]$$

In what follows it is required to know the number of combinations (also called the number of degrees of freedom) between the frequencies ν and $\nu + d\nu$. Differentiating the foregoing expression with respect to ν gives

$$dC'' = C''(\nu, \nu + d\nu) = 4\pi a^3\nu^2 d\nu/c^3 \ldots\ldots\ldots [23]$$

We have assumed in the beginning that when an electromagnetic wave is propagated along the X-axis, the electric intensity is directed along the Y-axis and the magnetic intensity along the Z-axis. Now we can imagine another wave of the same frequency, propagated along the X-axis, but with the directions of G and H turned by 90 deg. The new wave will in no way interfere with the first one, nor can the two be combined into one. Therefore, in addition to the waves represented by Eqs. [22] and [23], an equal number of other waves can coexist. The total number is double that given by these equations, and Eq. [23] becomes

$$dC' = C'(\nu, \nu + d\nu) = 8\pi K\nu^2 d\nu/c^3 \ldots\ldots\ldots [24]$$

where

$$K = a^3 \ldots\ldots\ldots\ldots [25]$$

is the volume of the enclosure. The reasoning which leads to Eq. [24] is due to Rayleigh and Jeans. While originally deduced for a cubic space, the formula was later proved to hold true for an enclosure of any shape. Eq. [24] refers to a space

of volume K. The number of degrees of freedom per unit volume is

$$dC = C(\nu, \nu + d\nu) = 8\pi\nu^2 d\nu/c^3 \qquad [26]$$

and this is the expression used by Bose in the deduction of Planck's formula.

Eqs. [24] and [26] merely determine the number of discrete waves whose frequencies lie between ν and $\nu + d\nu$ and which may coexist in the enclosure. They say nothing about the relative intensity of the waves, because the amplitude A, Eq. [18], has been canceled out in the substitution. This means that some of the waves within the range under consideration may be much more intense than the others, and some may be missing altogether. This is a point of fundamental importance because the very essence of Bose's method is to find the most probable number of photons within a given range of frequencies.

5 THE USE OF A REPRESENTATIVE MOMENTUM SPACE

When a certain amount of thermal radiation is in equilibrium within an enclosure, the density of energy may reasonably be assumed to be the same at all points. More accurately, the average distribution of photons of various wave lengths, directions, and intensities is the same at all points. The momentum p of a photon, Eq. [10], at a given instant is a vector. Consequently, the thermal radiation at a given point in space and at a given instant may be described by specifying the magnitudes and the directions of the momenta of all the photons passing through that point at that particular instant (Fig. 4). This leads to the concept of a representative momentum space (in our case a three-dimensional space) in which the three components of the momenta, p_x, p_y, and p_z are laid off parallel with some three mutually perpendicular axes.

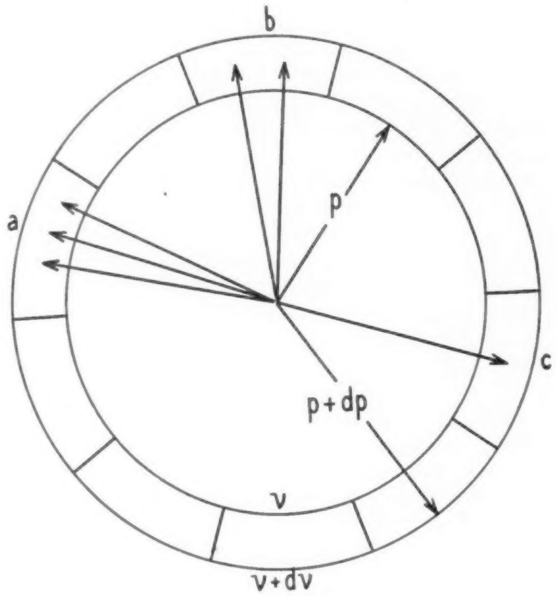


FIG. 4 A MOMENTUM SHELL IN A REPRESENTATIVE SPACE, SHOWING THE DISTRIBUTION OF VECTORIAL QUANTA IN CELLS

In Fig. 4 the vectors drawn are those of photons whose frequencies lie between ν and $\nu + d\nu$, and consequently the momenta have values between p and $p + dp$. Thus, in the representative space, the ends of all such vectors lie within a spherical shell bound by concentric surfaces of radii p and $p + dp$. We have seen before that frequencies of radiation vary in small but finite steps. We now make an additional assumption that the momenta vary in a discontinuous manner, not only in magnitude but in direction in space as well. This is in accordance with the general underlying idea of the quantum theory, and a similar assumption is used in the quantum mechanics of atoms and molecules.

To express this idea graphically, we divide the special shell in Fig. 4 into a number of cells of equal volume, and postulate that the vectors whose ends are in the same cell are indistinguishable from one another. All we can say is that the cell a is occupied by three photons, and the cell b by two photons, but if the three vectors within a were shifted or interchanged, there would be no way for us to know about this so long as the ends still remained within the cell a. Thus, each cell corresponds to a degree of freedom of radiation within the limits of frequency ν and $\nu + d\nu$, in the sense that when a vector of momentum changes from one cell to another, we call it a different kind of photon.

The inescapable conclusion is that the total number of cells within the shell under consideration is equal to dC, as given by Eq. [26], provided that Fig. 4 refers to momenta per unit volume of the enclosure shown in Fig. 1. An elementary computation will now enable us to determine the volume of a cell in the momentum space. The volume of the spherical shell is

$$dL = 4\pi p^2 dp \qquad [27]$$

Substituting for p its value from Eq. [10], this becomes

$$dL = 4\pi h^3 \nu^2 d\nu/c^3 \qquad [28]$$

A comparison with Eq. [26] shows that the two equations will agree if the volume of a cell in the momentum space be put equal to $0.5h^3$. Denoting this volume by ΔdL, we have

$$\Delta dL = 0.5h^3 \qquad [29]$$

It will be remembered that in changing from Eq. [23] to Eq. [24] photons polarized in two mutually perpendicular planes have been taken into account. Therefore, Eq. [26] also contains photons in pairs. Instead of stating that the volume of a cell is $h^3/2$ one may also say that the volume per cell is h^3, but each cell comprises photons of both kinds.

Consider now Eqs. [10], [26], [27], and [29]. Only three out of four are independent of each other, and any one may be obtained from the remaining three. We have deduced Eqs. [10], [26], and [27] from entirely separate considerations and found Eq. [29] as a consequence. Some writers assume Eq. [29] as a postulate and with the aid of Eqs. [10] and [27] deduce Eq. [26], thus doing away with the reasoning given in Section 4. Such a procedure seems somewhat more arbitrary than the one adopted in this article.

6 ON THE DISTRIBUTION OF PARTICLES IN CELLS

From an inspection of Fig. 4 the reader may anticipate that in the further study of the properties of thermal radiation we shall deal with two kinds of entities, namely, quantum cells and vectors of momentum. From a mathematical point of view the latter may be thought of as so many material points or particles to be distributed among a given number of cells. Therefore, in this purely statistical section of the article we shall deal simply with cells and particles without specifying their physical nature or meaning.

The actual numbers of cells and of quanta of radiation are enormously large; therefore, the final formulas have to be understood analytically, rather than visualized. However, it will help to follow the final reasoning if we first consider a few purely academic cases of distribution in which the number

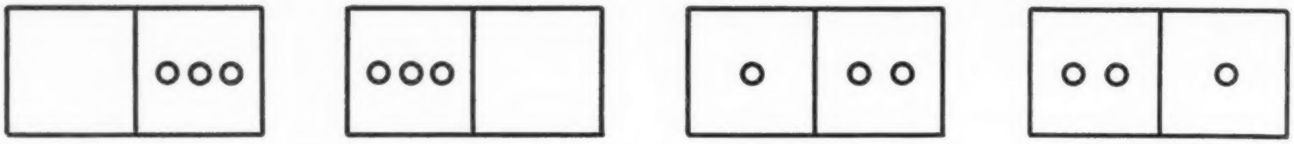


FIG. 5 ALL THE POSSIBLE ARRANGEMENTS OF THREE IDENTICAL (INDISTINGUISHABLE) PARTICLES IN TWO CELLS

of cells and the number of particles are sufficiently small to allow the results to be computed and expressed by numbers.

As a first example, consider the case of two cells and three particles, as shown in Fig. 5. Let the particles be identical, in the sense of being indistinguishable from each other, whereas let the cells be distinct. It is required to determine all the possible arrangements of the particles in the cells. There are altogether four distinct arrangements, as shown in Fig. 5 and in Table 1. The first arrangement consists in placing all the three particles in cell 2, and none in cell 1.

TABLE 1

$C = 2;\ N = 3;\ W = 4!/3! = 4$

0	3	$2! = 2$
3	0	
1	2	$2! = 2$
2	1	

With the second arrangement, all the three particles are in cell 1 and none in cell 2. With the third and fourth arrangements, two particles are in one cell and one in the other.

If the particles were distinguishable from one another, there would be many more arrangements of the type 1–2. Thus, let three persons, *A*, *B*, and *C*, be placed in two rooms, No. 1 and No. 2, there being one person in room No. 1 and two in room No. 2. Then, in place of the third line in Table 1 we would have three distinct lines, *A-BC*, *B-CA*, and *C-AB*. If the relative position of the two persons in room No. 2 is also a factor, then we should have six possible arrangements, namely, *A-BC*, *A-CB*, *B-CA*, *B-AC*, *C-AB*, and *C-BA*. The very basis of Bose's statistics is that the particles or photons are indistinguishable from one another so that there is only one arrangement represented by the third line in the table, and not three or six.

In Tables 1 to 6 the notation is as follows: C is the total number of cells, N is the total number of particles, and W is the total number of arrangements, that is, the number of horizontal lines in a table. W is computed according to Eq. [32] which is deduced later. Some writers speak of W as the probability (*Wahrscheinlichkeit*) but it seems preferable to speak of this quantity as of the total number of arrangements.

The computations in the last columns of the tables have been performed in accordance with Eq. [34] which is also proved later. This formula gives the number of arrangements with cells of prescribed types. For example, in Table 2 the first

TABLE 2

$C = 3;\ N = 2;\ W = 4!/(2!2!) = 6$

0	0	2	
0	2	0	$3!/2! = 3$
2	0	0	
0	1	1	
1	0	1	$3!/2! = 3$
1	1	0	

three lines represent all the possible arrangements in which one cell is occupied by two particles and the other two cells are empty. There are three such arrangements, and this agrees with the number computed from Eq. [34].

In Table 2, there are three cells and only two particles to be placed in them. It will be seen at once that there are two types of arrangements. In the first three arrangements, both particles are placed in one cell and the other two cells are empty. In the last three arrangements, two cells are occupied by one particle each, and the third cell is empty.

Table 3 illustrates some of the typical distributions of five particles in three cells. Altogether there are 21 possible arrangements, so that a complete table for this case consists of 21 horizontal lines of which only five are shown.

TABLE 3

$C = 3;\ N = 5;\ W = 7!/(5!2!) = 21$

0	0	5	$3!/2! = 3$
0	1	4	$3! = 6$
0	2	3	$3! = 6$
1	1	3	$3!/2! = 3$
1	2	2	$3!/2! = 3$

In the first line two cells are empty and the third contains all the five particles. There are three arrangements of this sort, depending on which of the three cells is occupied. There are six arrangements of the second and third kind, because there are six permutations of three different numbers, such as 0, 1, 4, or 0, 2, 3. The arrangements shown in lines 4 and 5 are similar to that in line 1, in that there are two cells with an equal number of particles. Since by assumption the particles are indistinguishable from one another, the number of different arrangements is only three for each line. It will be seen that an arrangement shown in the second or third line is twice as probable as one in any of the remaining lines because it can be realized in six different ways as against three for the latter. Numerically, the probabilities are $6/21 = 2/7$ and $3/21 = 1/7$, respectively.

The total number of arrangements W is equal to the sum of the numbers of arrangements V with specified types of cells. In other words

$$W = \Sigma V \qquad [30]$$

For example, in Table 3 we have $3 + 2 \times 6 + 2 \times 3 = 21$.

Table 4 illustrates a case when the number of particles is smaller than the number of cells. The three typical distributions possible are shown in the table. The total number of arrangements is 35, of which five are of the first kind, 20 of the second kind and 10 of the third kind. The probability of the second distribution is the greatest and is equal to $20/35 = 4/7$.

TABLE 4

$C = 5;\ N = 3;\ W = 7!/(3!4!) = 35$

0	0	0	0	3	$5!/4! = 5$
0	0	0	1	2	$5!/3! = 20$
0	0	1	1	1	$5!/(2!3!) = 10$

It will be seen that as the particles are allowed to diffuse from the end compartment to the others, the probability of distribution at first increases, reaches a maximum, and then again decreases. We are therefore justified in speaking of a most probable distribution.

Table 5 is similar to Table 3 in the sense that the number of particles is greater than that of cells, only both N and C are much larger. The total number of possible arrangements is

50,388, of which only a few typical ones are shown. Here again the effect of gradually spreading out the particles over more and more cells is at first to increase the number of possible arrangements.

TABLE 5

$C = 8$; $N = 12$; $W = 19!/(12!7!) = 50{,}388$

0	0	0	0	0	0	0	12	$8!/7! = 8$
0	0	0	0	0	0	1	11	$8!/6! = 56$
0	0	0	0	0	1	2	9	$8!/5! = 336$
0	0	0	0	1	2	3	6	$8!/4! = 1680$
0	0	0	1	2	2	3	4	$8!/(3!2!) = 3360$
0	0	1	1	1	2	3	4	$8!/(3!2!) = 3360$
0	1	1	1	1	2	3	3	$8!/(4!2!) = 840$
1	1	1	1	2	2	2	2	$8!/(4!4!) = 70$
1	1	1	1	1	1	3	3	$8!/(6!2!) = 28$

A maximum is reached with 3360 arrangements of a prescribed type after which the probability or the number of arrangements rapidly decreases. Table 6 is similar to Table 4 and needs no explanation.

TABLE 6

$C = 12$; $N = 8$; $W = 19!/(8!11!) = 75{,}582$

0	0	0	0	0	0	0	0	0	0	0	8	$12!/11! = 12$
0	0	0	0	0	0	0	0	0	0	1	7	$12!/10! = 132$
0	0	0	0	0	0	0	0	0	1	2	5	$12!/9! = 1320$
0	0	0	0	0	0	0	0	1	2	2	3	$12!/(8!2!) = 5940$
0	0	0	0	0	0	0	1	1	2	2	2	$12!/(7!3!2!) = 7920$
0	0	0	0	0	0	1	1	1	1	2	2	$12!/(6!4!2!) = 13860$
0	0	0	0	0	1	1	1	1	1	1	2	$12!/(5!6!) = 5544$
0	0	0	0	1	1	1	1	1	1	1	1	$12!/(4!8!) = 495$

After these preliminary numerical examples, let us consider the general case of N particles to be placed in C cells. It is required to deduce two formulas, one for the total number of possible arrangements (the value of W at the head of each table) and another for the number of arrangements with a prescribed number of particles in each cell (the numbers to the right of each horizontal line in Tables 3 to 6).

TOTAL NUMBER OF ARRANGEMENTS

Consider C cells side by side and N identical particles to be placed in them in all possible combinations. To illustrate the method of counting separate arrangements, cells 15 and 16 in one of the arrangements are shown in Fig. 6 with five particles a, b, c, d, and e. We shall assume that the distribution of particles remains the same in the rest of the cells and need not be considered here. The arrangement A is different from that of B because the numbers of particles in each cell are different. In other words, each cell has its individuality and when the numbers of particles in any two cells are interchanged, this counts as a separate arrangement. On the other hand, the arrangements B and C count as one, because only the particles b and c are interchanged and by assumption the particles have no distinguishable identity.

To compute the total number of arrangements, consider all the cells (1, 2, 3, etc.) and all the particles (a, b, c, etc.) arranged in a circle, Fig. 7. The diagram is to be read clockwise and all the particles following a cell are understood to be within that cell. Thus cell 1 contains particles a, b, c, cell 2 particle d, cell 4 is empty, etc. In rearranging the cells and the particles we shall keep cell 1 stationary, because it is the order of the cells and not their absolute position on the circle that determines an arrangement.

Keeping cell 1 stationary and considering the remaining $C - 1$ cells and N particles as individual movable objects, we can make D permutations, where

$$D = (N + C - 1)! \qquad [31]$$

This is an application of the fundamental formula in algebra that with n objects $n!$ permutations are possible. However, in this formula it is assumed that each object is distinguishable from the rest. In our case, with a given arrangement of the cells we can interchange any particles without producing a new arrangement, because the particles are not distinguishable from one another. The number of permutations of N particles by themselves is $N!$, and therefore the foregoing

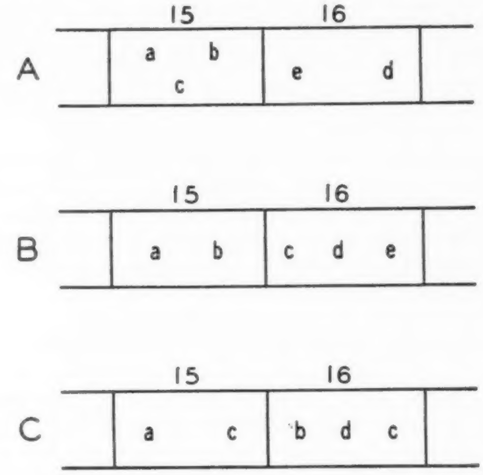


FIG. 6 SOME REARRANGEMENTS OF FIVE INDIVIDUAL (DISTINGUISHABLE) PARTICLES IN TWO CELLS

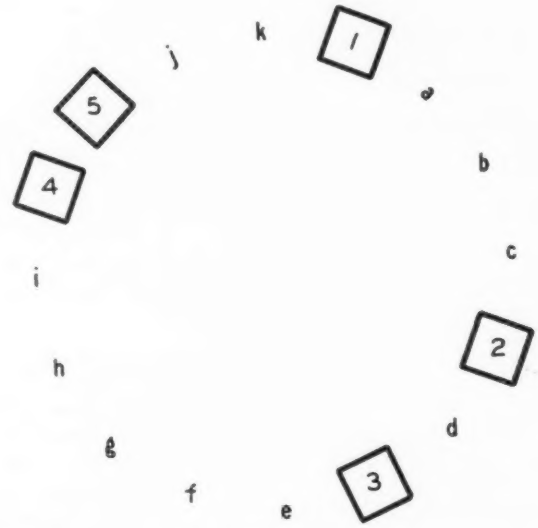


FIG. 7 A CIRCULAR SEQUENCE OF FIVE CELLS AND ELEVEN PARTICLES

expression for D must be divided by $N!$ to eliminate the superfluous combinations.

Consider now the particular arrangement shown in Fig. 7 and some others which differ from it only in the order of the cells; for example, one in which cell 3 is interchanged with cell 2. All such arrangements, while included in expression [31], are ruled out because in our particular case the positions of the cells are fixed, whereas Eq. [31] refers to $(N + C - 1)$ objects all of which are movable. There are $(C - 1)!$ possible permutations of $(C - 1)$ cells, so that expression [31] must be divided by $(C - 1)!$ to eliminate the impossible combinations. Thus the final formula for the number of arrange-

ments of N identical movable particles in C fixed individual cells is

$$W = (N + C - 1)!/[N!(C - 1)!] \ldots\ldots\ldots [32]$$

This is the formula used at the top of each table and also is the basis of Bose's statistics (1, 17).

NUMBER OF ARRANGEMENTS OF A PRESCRIBED TYFE

Let C be again the total number of cells and let Z_0, Z_1, Z_2, etc., be the numbers of cells containing 0, 1, 2, etc., particles each. For example, in Table 6, line 4, $Z_0 = 8$; $Z_1 = 1$; $Z_2 = 2$; $Z_3 = 1$. It is required to determine the number of arrangements possible with the given values of C, Z_0, Z_1, Z_2, etc., where

$$C = \Sigma Z \ldots\ldots\ldots\ldots\ldots\ldots [33]$$

The cells being fixed, we can only change the numbers of particles assigned to each individual cell, in various combinations. For example, in Table 2, in the first three lines, we have three numbers 0, 0, 2 which must be arranged in all the possible ways. The total number of permutations of C different numbers is $C!$. This will be the required number of arrangements, provided that all the numbers, Z_0, Z_1, Z_2, etc., are equal to 1, that is, each cell contains a different number of particles. In Table 3, the second and the third lines illustrate this case. When however, one of the Z's is equal to 2 or is greater than 2, as for example in the last line of Table 3, interchanging two equal numbers will not give a new arrangement, because, by assumption, particles are indistiguishable from one another. But the number of permutations of Z objects is $Z!$. Therefore, $C!$ must be divided by $Z!$ to eliminate identical arrangements. As a rule several Z's may be greater than 1. Thus, in Table 5, line 2, $Z_0 = 6$, $Z_1 = 3$. Therefore, the general formula sought is

$$V = C!/(Z_0!Z_1!Z_2!, \text{etc.}) \ldots\ldots\ldots\ldots [34]$$

This is the formula used in the last columns of Tables 1 and 2, and to the right of each horizontal line in the remaining tables. Formula [34] may also be written in the form

$$V = C!/\Pi Z_r! \ldots\ldots\ldots\ldots\ldots [35]$$

where the symbol Π stands for the word "product" and the subscript r means 0, 1, 2, etc. This formula is used also in Bose's statistics of quanta (9, 15).

7 STIRLING'S THEOREM ABOUT LARGE FACTORIALS

Formulas [32] and [34] contain factorials of very large numbers. In the deduction of Planck's formula it is necessary to differentiate such expressions. This is done by first replacing the factorials by their approximate values which can be readily differentiated. Consider the factorial $n!$ of a very large number n. If $n!$ be replaced by the expression $n^n\epsilon^{-n}\sqrt{2\pi n}$, the true value will have been divided by a number lying between 1 and $1 + (10n)^{-1}$. Therefore, approximately

$$n! = n^n\epsilon^{-n}\sqrt{2\pi n} \ldots\ldots\ldots\ldots [36]$$

which is known as Stirling's theorem. For a detailed proof of this formula see, for example, (8).

Since the gamma function of a positive integer can be represented by a factorial, some proofs of Stirling's theorem may be found under methods of evaluating $\Gamma(x + 1)$ when x is a large positive integer. See for example (6 and 14).

In what follows, Eqs. [32] and [34] are written for a large number of infinitesimal shells, one of which is shown in Fig. 4, and a product of such expressions is taken before differentiating them. Therefore, it is more convenient to deal with $\log n!$ than with $n!$, because then instead of a product of factorials one has a sum of their logarithms. Eq. [36] gives

$$\log n! = n \log n - n - 0.5 \log (2\pi n) \ldots\ldots [37]$$

natural logarithms being understood. When n is large, the last term is negligible, so that to a good degree of approximation we may write

$$\log n! = n \log n - n \ldots\ldots\ldots\ldots\ldots [38]$$

This is the formula which is used later.

The validity of Eq. [38] may be briefly demonstrated as follows: We have

$$n! = n(n - 1)!$$

Hence

$$\log n! = \log n + \log (n - 1)!$$

Put

$$\log n! = f(n)$$

then

$$f(n) = \log n + f(n - 1)$$

The form of this expression suggests Taylor's expansion, provided that n is very large so that 1 may be considered as a small increment of n. Taylor's formula, which may be found in any treatise on differential calculus, is

$$f(x + y) = f(x) + (y/1!)f'(x) + (y^2/2!)f''(x) + \text{etc.}$$

where $f'(x)$, $f''(x)$, etc., are the first, second, etc., derivatives of the function $f(x)$ with respect to x. Put $x = n$ and $y = -1$ so that

$$f(n - 1) = f(n) - f'(n) + \text{etc.}$$

Neglecting the remaining terms and comparing this expression with the preceding one, we find that

$$f'(n) = \log n \ldots\ldots\ldots\ldots\ldots\ldots [38a]$$

Taking a derivative of both sides of Eq. [38] with respect to n, the result will be found to be identical with this expression. In other words, Eq. [38] could be obtained by integrating Eq. [38a].

8 THE RELATIVE MAXIMUM OF A PRODUCT OF FACTORIALS

It will be shown later that one of the steps in the deduction of Planck's formula is as follows: Write the expression [32] for various spherical layers in the momentum space (one of the shells or layers being shown in Fig. 4), using a different N and a different C for each layer. Take a product of such expressions for all the layers in the problem, thus obtaining a formula of the type

$$W_t = \Pi \frac{(N + C - 1)!}{N!(C - 1)!} \ldots\ldots\ldots\ldots [39]$$

where the symbol Π stands for the word "product" and the subscript t means "total." Consider all the C's as constant and all the N's as variable, but connected by the condition

$$\Sigma EN = E_t \ldots\ldots\ldots\ldots\ldots\ldots [40]$$

It will be shown later that in Bose's statistics E_t is the total energy of radiation and E is the energy associated with an individual photon. In Eq. [40] the quantity E_t, and all the

E's are known constants, and the summation is extended over all the shells. It is required to determine values of N's which convert W_t into a maximum and at the same time satisfy Eq. [40].

We are not concerned as yet with the physical reasons for such a procedure, but only with the mathematical method of obtaining the relative maximum of W_t. Instead of trying to determine the conditions for the maximum of W_t we shall determine those for the maximum of $\log W_t$, since a logarithm reaches a maximum when the corresponding number reaches its maximum. It is preferable to operate on $\log W_t$ because the product Π is then replaced by a sum Σ, with the same meaning as in Eq. [40]. Since in our problem C is always a very large number, it is permissible to write C in place of $C - 1$, especially in view of the fact that we are going to use Stirling's approximate formula anyway. Thus Eq. [39] becomes

$$\log W_t = \Sigma \log (N + C)! - \Sigma \log N! - \Sigma \log C! \ldots [41]$$

We now replace the factorials containing N by their approximate values in accordance with Eq. [38], and obtain

$$\log W_t = \Sigma[(N + C) \log (N + C) - (N + C)] - \Sigma(N \log N - N - \Sigma \log C!) \ldots\ldots [42]$$

Equating to zero the total differential of this expression with respect to all the N's gives

$$d \log W_t = \Sigma[\log (N + C) - \log N]dN = 0 \ \ldots [43]$$

Condition [40] after differentiation gives

$$\Sigma E dN = 0 \ldots\ldots [44]$$

According to the usual rule of finding a relative maximum (see a treatise on differential calculus), we multiply Eq. [44] by an undetermined factor, say $-q$, and add it to Eq. [43]. The result is

$$\Sigma[\log(N + C)/N - qE]dN = 0 \ldots\ldots [45]$$

In this expression, all the N's are now independent variables, whereas in Eq. [39] they are subject to condition [40]. In Eq. [45] the condition [40] has been incorporated by means of the undetermined multiplier q. Since in Eq. [45] all the increments dN are arbitrary, the sum can be equal to zero only if the coefficient of each dN is separately equal to zero. Thus, for each N

$$\log (N + C)/N - qE = 0 \ldots\ldots [46]$$

from which

$$N = C/[\exp (qE) - 1] \ldots\ldots [47]$$

The factor q cannot be determined from the given data of the problem and will be deduced in section 10 from thermodynamic considerations, see Eq. [91].

The result [47] is the solution sought; for each layer it gives an expression for N in terms of the given values of C and E.

9 THE RELATIVE MINIMUM OF A PRODUCT OF FACTORIALS

An alternative method of deducing Planck's formula consists in using Eq. [34] in place of [32]. Here again this formula is written for all the spherical layers in the momentum space. A product of all these expressions is taken and an expression deduced for its relative maximum under certain limiting conditions. Thus, the expression of which an extremum is sought is

$$V_t = \Pi(C!/\Pi_r Z_r!) \ldots\ldots [48]$$

In this expression, the subscript r stands for 0, 1, 2, etc., so that the expression within the parentheses signifies operations to be performed within a shell or layer. The Π without a subscript denotes taking products over the individual shells. Since all the C's are to be considered constant, finding a maximum of expression [48] is equivalent to determining a minimum of its denominator. Denoting this denominator by U_t, we have

$$U_t = \Pi(\Pi_r Z_r!) \ldots\ldots [48a]$$

As will be explained later, the limiting conditions in this case are

$$\Sigma_r Z_r = C \ldots\ldots [49]$$

$$\Sigma_r r Z_r = N \ldots\ldots [50]$$

$$\Sigma EN = E_t \ldots\ldots [51]$$

The Z's and the N's are variable quantities, whereas the C's, the E's, and E_t are known constants. The coefficient r in Eq. [50] has the values 1, 2, 3, etc., quite apart from the physical meaning of these equations. We are concerned here with a purely mathematical problem of finding a relative minimum of expression [48], the variables being subject to conditions [49] to [51].

By assumption, all the Z's are such large quantities that Stirling's approximation [38] may be used. Therefore, it is more convenient to establish a condition for a minimum of $\log U_t$, rather than U_t itself. We have

$$\log U_t = \Sigma\Sigma_r \log Z_r! \ldots\ldots [52]$$

or, using Stirling's formula,

$$\log U_t = \Sigma\Sigma_r(Z_r \log Z_r - Z_r) \ldots\ldots [53]$$

Equating to zero the complete differential of this expression, we obtain

$$d \log U_t = \Sigma\Sigma_r \log Z_r dZ_r = 0 \ldots\ldots [54]$$

The conditions [49], [50], and [51], after differentiation give

$$\Sigma_r dZ_r = 0 \ldots\ldots [55]$$

$$\Sigma_r r dZ_r = dN \ldots\ldots [56]$$

$$\Sigma E dN = 0 \ldots\ldots [57]$$

From Eqs. [56] and [57] all the dN's can be eliminated by multiplying Eq. [56] by E and taking a summation of both sides in accordance with Eq. [57]. The result is

$$\Sigma\Sigma_r E r dZ_r = 0 \ldots\ldots [58]$$

We now have Eq. [54] for a minimum, with the limiting conditions [55] and [58]. Multiplying the latter two equations by undetermined factors, $-\log B$ and q, respectively, and adding to Eq. [54], gives

$$\Sigma\Sigma_r(\log Z_r - \log B + qEr)dZ_r = 0 \ldots\ldots [59]$$

In this expression, all the increments dZ_r are now independent of one another and consequently the coefficient of each must be equal to zero separately. The typical condition is

$$\log (Z_r/B) + qEr = 0 \ldots\ldots [60]$$

from which

$$Z_r = B \exp (-qEr) \ldots\ldots [61]$$

This is the required relationship between each Z and the constants of the problem for a minimum of U_t.

To eliminate B, substitute the value of Z_r from Eq. [61] in Eq. [49]. The result is

$$C = B\Sigma \exp(-qEr) \ldots\ldots\ldots\ldots\ldots [62]$$

The summation on the right-hand side of Eq. [62] is a geometric progression; in accordance with the well-known formula of algebra, when the limits of r are zero and infinity, we have

$$\sum_{r=0}^{r=\infty} \exp(-qEr) = [1 - \exp(-qE)]^{-1} \ldots\ldots [63]$$

In reality, the limits of r are zero and some large number, but since the series is rapidly convergent the difference between the values of the sum when the upper limit is infinity and a large number is negligible. Substituting the value of the sum from Eq. [63] in Eq. [62] and solving for B, we obtain

$$B = C[1 - \exp(-qE)] \ldots\ldots\ldots\ldots\ldots [64]$$

Therefore, the final expression for Z_r is

$$Z_r = C[1 - \exp(-qE)] \exp(-qE) \ldots\ldots\ldots [65]$$

The value of q cannot be determined from the data of the problem. It will be shown in section 10 that q may be found from thermodynamic considerations, see Eq. [91].

To deduce an expression for N, substitute the value of Z_r from Eq. [65] in Eq. [50]; this will give

$$N = C[1 - \exp(-qE)] \Sigma r \exp(-qE) \ldots\ldots [66]$$

Assuming again that r varies from zero to infinity, we have

$$\sum_{r=0}^{r=\infty} r \exp(-qEr) = \exp(-qEr)/[1 - \exp(-qE)]^2 \ldots [67]$$

This formula may be proved by actually performing the division on the right side. Hence

$$N = C \exp(-qE)/[1 - \exp(-qE)] = C/[\exp(qE) - 1] \ldots [68]$$

Since this formula is identical with Eq. [47], we have reached a somewhat unexpected result that two seemingly different expressions, [39] and [48], have the same condition for their maxima. This subject will be discussed later when we come to the physical side of Bose's statistics.

10 ENTROPY AND PROBABILITY OF STATE

The purpose of this section is to deduce the value of the factor q which enters in Eqs. [47] and [68]. For this purpose it will be necessary to go into the fundamentals of the classical thermodynamics of perfect gases, since Bose simply uses the same value as is used there. This procedure is mainly justified by the fact that this value gives the required exponent in Eqs. [1] and [2], and we know that these expressions agree quite well with the experimental data.

Let dQ be the amount of heat communicated to a gram molecule of a perfect gas; we then have

$$dQ = c_v\, dT + P dv \ldots\ldots\ldots\ldots\ldots\ldots [69]$$

where c_v is the specific heat at constant volume, T the temperature, P the gas pressure, and v the volume of the gas. The first term on the right-hand side represents the increase in the internal energy of the gas accompanied by a rise in temperature, while the second term represents the external work done. We shall assume that work and heat are expressed in the same units so that no conversion factor is needed in front of Pdv.

The expression on the right-hand side is not a perfect differential, but becomes one after division by T. We thus have

$$dS = c_v dT/T + Pdv/T \ldots\ldots\ldots\ldots [70]$$

where the quantity

$$dS = dQ/T \ldots\ldots\ldots\ldots\ldots\ldots\ldots [71]$$

is known as the increase in the entropy of the gas. The reader may refresh his memory on the significance of entropy by looking up the Carnot process in some elementary book on thermodynamics.

The fundamental equation of the perfect gaseous state is

$$Pv = RT \ldots\ldots\ldots\ldots\ldots\ldots\ldots [72]$$

where R is a universal constant, provided that v refers to one gram molecule of the substance. Substituting the value of P/T from Eq. [72] in Eq. [70], we obtain

$$dS = c_v dT/T + Rdv/v \ldots\ldots\ldots\ldots\ldots [73]$$

The right-hand side of this equation is readily integrable, so that dS is a perfect differential. This means that the entropy S characterizes a state of gas and that an increase in the entropy between any two states is a function of the characteristics of these two states only and not of the path between them nor the external work done. In this respect dS differs fundamentally from dQ, because the latter contains the term Pdv which is not a perfect differential.

With the development of the kinetic theory of gases, based upon the concept of collisions among molecules and bombardment of the walls of the containing vessel, another definition and interpretation of entropy gradually gained foothold, namely the idea that in some manner the entropy of a state characterizes the relative probability of that state of gas. Without going into the details (1, 22), the general reasoning may be stated as follows: Let initially the different portions of a quantity of gas be at different pressures and temperatures and let these be allowed to equalize. With a random motion and irregular collisions of molecules a strictly permanent state (microscopically speaking) is inconceivable. However, the actual successive states, meaning by this combinations of instantaneous positions and velocities of the individual particles, fluctuate about a certain average or most probable combination.

Each particular state of gas may be realized in a number of ways, as illustrated in the tables in Section 6. Therefore it is possible to speak of mathematical or thermodynamic probability of a state, meaning by this the number of ways in which it may be realized by interchanging individual molecules. Thus, there are more probable and less probable states; besides, there is the most probable state and the average state. It is known from thermodynamics that during an irreversible process, like the one under consideration, the entropy increases. On the other hand, an equalization of pressures or temperatures means a change from a less probable to a more probable state. Hence we may say that in general, when the probability of a state increases, the total entropy of the substance also increases.

However, entropy is not proportional to the probability and the two vary in a different manner. The combined probability of two independent events, taking place simultaneously, is equal to the product of their single probabilities. For example, let Mr. A spend on the average one third of his time in a given city. The probability of finding him there on a given day is $^1/_3$. It rains in that city one day out of eleven. Hence the probability that it will rain on a given day is $^1/_{11}$. Now, the probability of finding Mr. A in that city on a rainy day is

$(^1/_3) \times (^1/_{11}) = ^1/_{33}$, provided that Mr. A's movements from city to city are not influenced by the occurrence or nonoccurrence of rain.

More generally, if the probability of an event is $p_1 = f_1/t_1$ and the probability of another totally independent event is $p_2 = f_2/t_2$, the combined probability, that is, the probability of the two events taking place concurrently, is

$$p_{12} = f_1 f_2/t_1 t_2 \qquad [74]$$

In these expressions f_1 and f_2 are the numbers of favorable events, and t_1 and t_2 are the total numbers of events. Any one of the f_1 events may be combined with any one of f_2 events, so that the total number of combined favorable events is $f_1 f_2$. Similarly the total number of events is $t_1 t_2$. This proves Eq. [74]. This formula may be readily extended to any number of independent events, giving a more general formula for the total probability p_t of a complex event

$$p_t = \Pi p_i \qquad [75]$$

the symbol Π signifying "product."

In application to the kinetic theory of gases, this means that a given quantity of gas may be divided into groups of molecules, and the probability p_i of the state of the ith group determined separately, using here the term probability in a thermodynamic sense, that is, the number of ways in which a particular combination of coordinates and momenta may be realized. The combined probability p_t for the whole quantity of gas is then expressed by Eq. [75].

On the other hand, theory and experience show that entropy is additive and not multiplicative in character; that is, if the entropies of the separate portions of the gas at a certain instant are s_1, s_2, etc., the total entropy is

$$S = \Sigma s_i \qquad [76]$$

It will be seen at once that Eqs. [75] and [76] may be satisfied simultaneously by putting

$$s_i = k \log p_i \qquad [77]$$

where k is some universal constant. The entropies are added when the probabilities are multiplied. Eq. [77] gives

$$\Sigma s_i = k\Sigma \log p_i = k \log (\Pi p_i) \qquad [78]$$

so that

$$S = k \log p_{t\,\max} + \text{const} \qquad [79]$$

A constant is added because in classical thermodynamics (as distinct from some modern forms of statistical mechanics) the entropy of an aggregate can be known only to an additive constant. $p_{t\,\max}$ is used in place of p_t because the entropy of the actual stable condition of gas is meant. This condition is the most probable state or, more accurately, an average state almost indistinguishable from it.

By considering the actual Maxwellian distribution of velocities among the molecules of a gas, the most probable distribution may be found by using a method similar to that given in Sections 8 and 9. The result for the entropy is of the form (12)

$$S = kN_0 \log (T^{1.5} v) + \text{const} \qquad [80]$$

where N_0 is the number of molecules per gram-molecule. It would lead us too far to give here a deduction of this formula, because it would mean a review of a considerable portion of the classical kinetic theory of gases and because after all, the assumption by Planck and Bose that the same value of k holds true for quanta of radiation is only a hypothesis justified by the results and not by an a priori reasoning. Differentiating Eq. [80], we obtain

$$dS = 1.5\, kN_0\, dT/T + kN_0\, dv/v \qquad [81]$$

Comparing [73] and [81], we find at once that

$$c_v = 1.5\, kN_0 \qquad [82]$$

$$R = kN_0 \qquad [83]$$

From these equations

$$k = R/N_0 \qquad [84]$$

$$R = c_v/1.5 \qquad [85]$$

Thus, knowing the specific heat of a gas at constant volume, the universal gas constant R may be computed from Eq. [85] and then k determined from Eq. [84].

While any value of k will do in Eq. [79] so long as we deal only with entropy and probabilities of state, this constant must have the particular value, according to Eq. [84], in order to agree with thermodynamic changes in the gas as a whole.

Now, Bose assumes that the entropy of thermal radiation is also expressed by Eq. [79] and that the coefficient of proportionality k is the same as for a perfect gas, that is, according to Eq. [84]. The only difference lies in the method of expressing p_t and consequently in the value of $p_{t\,\max}$. The physical side of Bose's theory is considered in the next section. For our present purposes it is sufficient to state that his probability is expressed by Eq. [39]. Consequently, the entropy is given by Eq. [42] multiplied by k, and from Eq. [43] we may write

$$dS = k\, \Sigma \log [(N + C)/N] dN \qquad [86]$$

From Eq. [47]

$$(N + C)/N = \exp (qE) \qquad [87]$$

therefore

$$dS = kq\Sigma E dN \qquad [88]$$

We now assume that the increments dN are such as to change the value of the total energy E_t. Hence

$$\Sigma E dN = dE_t \qquad [89]$$

But, from Eq. [71], assuming it to hold true for thermal radiation

$$dE_t/T = dS \qquad [90]$$

Multiplying Eqs. [88], [89], and [90] term by term, we find that

$$q = 1/kT \qquad [91]$$

This is the value of q to be used in Eq. [47]. By a similar reasoning, the same value of q may be found for Eq. [68].

11 BOSE'S DEDUCTION OF PLANCK'S EQUATION [2]

The reader is now prepared to follow Bose's argument without various mathematical transformations already performed in the preceding sections. The formulas used in what follows are numbered as in the foregoing sections, making a search through the article unnecessary, unless the reader wishes to refresh his memory as to meaning or method of proof.

The phenomenon under consideration (Fig. 1) is pictured as follows: An enclosure with perfectly reflecting walls is maintained at an absolute temperature T and the thermal radiation within it is assumed to have reached a steady state of statistical equilibrium. This radiation we shall conceive of as consisting

of discrete electromagnetic pulses, or photons, of different frequencies, repeatedly reflected from the walls. In reality the walls are imperfectly reflecting, and we shall therefore assume that somewhere within the enclosure there is a very small speck of matter capable of absorbing and emitting photons. This will provide for a constantly changing total number of photons and constantly changing frequencies, at the same time keeping the total energy of enclosed radiation constant. The individual photons are supposed in no wise to interact or interfere with one another.

These photons are propagated at the velocity of light, and their frequencies theoretically range from zero to infinity. A photon of frequency ν is associated with an amount of energy

$$E = \nu h \qquad [6]$$

and its momentum is

$$p = \nu h/c \qquad [10]$$

The photons are assumed to be distributed uniformly within the enclosure, so that it is immaterial at what element of volume their distribution is studied. The distribution of their momenta in space at a point is yet to be ascertained. In other words, the first part of the problem is to find the relative numbers of photons of different frequencies and directions in a small portion of the hollow space.

We shall first concentrate our attention on photons whose frequencies lie between ν and $\nu + d\nu$ and make use of the representative momentum space shown in Fig. 4. The use of this space and the relationships resulting therefrom are explained in Section 4. The net result is that the total number of space cells in which the ends of the momentum vectors lie is

$$dC = C(\nu, \nu + d\nu) = 8\pi\nu^2 d\nu/c^3 \qquad [26]$$

From the physical point of view this is the number of degrees of freedom of radiation whose frequency lies between ν and $\nu + d\nu$. In other words, although the momenta of all these photons are numerically almost the same, there are dC equal and uniformly distributed cells in the shell shown in Fig. 4, all situated in one layer, and the vectors of the momenta can be distinguished only with reference to the particular cells which they happen to occupy. So long as a vector changes its direction without its end leaving a particular cell, the vector remains stationary in so far as our mathematical theory is concerned. This is an assumption in line with the general spirit of discontinuity introduced by the quantum theory of energy. Some cells may at a given instant be occupied by more than one vector and some may be empty. The added assumption that the number of particles per cell can be only one or zero has been used by Fermi in his statistical mechanics, but is not a part of Bose's theory. See footnote, page 490.

To illustrate the partition of vectors into cells, consider a hotel in which some guests at times move from one room to another. So long as a guest moves within his assigned room, his record in the guest book remains the same. The hotel management takes cognizance of his movements only when he signifies his desire to be transferred to another room or to check out.

Continuing the use of the momentum space, we now must think of many other layers of cells, inside and outside the one under consideration, each corresponding to some small range of frequencies, and extending from zero to infinity. In contradistinction to material particles, photons are assumed to be constantly absorbed and created so that their total number N_t is variable. However, their total energy E_t remains constant. Let the average energy per photon within the range of frequencies between ν and $\nu + d\nu$ be $E = \nu h$, and let the corresponding number of photons at a given instant be N. Then we have

$$\Sigma EN = E_t \qquad [40]$$

the summation to be extended over all the concentric spherical layers in the representative momentum space. No matter how the individual N's and the total N_t vary from instant to instant, the limiting condition [40] must always be fulfilled.

We shall now consider various possible distributions of N_t photons within different layers of cells and also within the cells of a given layer. The purpose of this analysis is to find a distribution which can be realized in the largest possible number of ways, as illustrated by the tables in Section 6. An arrangement which can be realized in the largest number of ways is the most probable arrangement, and we may safely assume it to be the actual distribution, since the total entropy of the enclosed radiation is then a maximum (Section 10).

This process of comparing different distributions of particles in cells and finding the most probable distribution dates from the early kinetic theory of gases. In that theory, each molecule of gas was assumed to possess an individual identity as though it were labeled with a letter, or a number. Therefore, when two molecules in two different cells were interchanged, as for example particles b and c in the lines B and C of Fig. 6, a new arrangement was created. Now Bose makes a different assumption, namely that photons of the same frequency are indistinguishable from one another so that interchanging the places of two of them in different cells of the same layer does not create a new combination because we have no way of distinguishing it from the other. Hence, in Bose's statistics the arrangements B and C count as one and not as two. This of course gives an entirely different mathematical result from the classical theory, and until we know more about the physical nature of photons this result is justified only by the fact that it leads to Planck's formula [2] which closely agrees with the available experimental data. For the difference between the classical and Bose's statistics see (9, 17).

Until we actually use the expression on the right-hand side of Eq. [26], we shall call the left-hand side simply C, instead of dC. Thus, in a particular shell (Fig. 4) we have C cells occupying distinct positions and N identical photons to be placed in these cells in all possible combinations. As explained in Section 6, the total number of such combinations W is expressed by Eq. [32]. The number of cells C being very large, unity may be neglected in comparison with it, and we have

$$W = (N + C)!/N!C! \qquad [32a]$$

Lest the reader be apprehensive in regard to the seemingly highhanded procedure of first calling an infinitesimal amount dC then simply C and finally saying that it is very large and neglecting unity in comparison with it, the following explanation may not be out of place. In problems involving discrete ultimate units of matter, electricity, or radiation, differentials are used in a sense quite different from that in classical physics where a box $dx\,dy\,dz$ can be imagined as being smaller than any specified small volume. In modern physics, a box $dx\,dy\,dz$ may contain a very large number of electrons, photons, or other discrete particles, each of which has a finite magnitude. We thus have an apparent anomaly of finite quantities being smaller than an infinitesimal quantity.

The explanation lies in the fact that we use the differential calculus only for "macrocosmic" continua; that is, for such large aggregates of elementary particles at close distances from each other that even "infinitesimal" changes comprise many such particles. For example, in order that a volume $dx\,dy\,dz$ of gas still behave like a gas of definite pressure and not as a

system of free moving bodies, this volume must contain a large number of gas molecules.

Eq. [32a] refers to a particular layer. A similar expression for thermodynamic probability (as W is sometimes called) may be written for each layer. The combined probability of a compound event consisting of independent events is equal to a product of the component probabilities. (See Section 10.) Therefore, the total number of arrangements W_t of photons in the cells of all the layers is expressed by Eq. [39]. Neglecting again 1 in comparison with C, we have

$$W_t = \Pi \{(N+C)!/(N!C!)\} \ldots\ldots\ldots\ldots [39a]$$

the multiplication Π being extended over all the layers in the momentum space, from zero to infinity. All the C's are constant and all the N's are variable, subject to the energy condition [40].

In the course of time, the number of photons in each cell and in each layer changes. Even the total number of photons changes. Those combinations of the numbers N which allow a given distribution in a larger number of ways occur more frequently, that is, they give larger values of W_t. Therefore, it is permissible to speak of the most probable distribution of the photons, that is, to determine a maximum of W_t. Such a distribution comes the nearest to the actual "average" distribution. In fact, unless the values of W_t on both sides of the most probable distribution fall off rapidly, the most probable distribution becomes almost indistinguishable from the average distribution. Even with a small number of particles, shown in Table 6, the number of combinations in the first two lines and in the last line are so small as to be negligible in comparison with the total number 75,582. The distributions shown in the lines 4 to 7 constitute the bulk of typical distributions and do not differ much from each other. As the number of particles and cells is increased to millions, the maximum of W_t becomes less and less sharply defined, and it therefore becomes permissible to speak of the most probable distribution as being also the actual average distribution, the fluctuations between the two being small.

A method has also been developed for a direct determination of the average distribution (10, 11, 23) in place of the most probable one. However, the mathematical theory employed is quite involved and since the final result is the same as that obtained in this article, we shall not go into it. It must also be remembered that in obtaining a maximum of expression [39a] Stirling's approximate formula is used for the factorials so that the result does not necessarily give the most probable distribution but only one which is not very different from it. For a general discussion of this question see (21) of the bibliography.

The method of obtaining a maximum of W_t, according to formula [39] or [39a], with the limiting condition [40], is explained in Section 8; the result is

$$N = C/[\exp(qE) - 1] \ldots\ldots\ldots\ldots [47]$$

where C is written for dC, as previously explained

$$q = 1/kT \ldots\ldots\ldots\ldots [91]$$

and

$$E = \nu h \ldots\ldots\ldots\ldots [6]$$

Formula [47] gives the number of photons N for a layer characterized by the number of cells dC and the average energy E per photon. With these values of N's used in Eq. [39a], W_t becomes a maximum. But the number of cells per unit volume of the enclosure, within the energy limits E and $E + dE$, is given by Eq. [26]. The energy per photon is $E = \nu h$. Hence, the density of energy of radiation within the frequency limits ν and $\nu + d\nu$ is

$$\psi_\nu d\nu = N\nu h = (8\pi\nu^2 d\nu/c^3)\nu h/[\exp(\nu h/kT) - 1] \ldots\ldots [2]$$

This formula is identical with Planck's formula [2] which thus follows from Bose's statistics in a natural manner.

Planck's formula can also be deduced on the basis of Bose's principle using a somewhat different reasoning. This method will now be indicated for the sake of completeness because Bose himself and some other writers have employed it. The difference between the two methods may be explained with reference to Tables 5 and 6.

For the sake of illustration, assume that we have only two energy levels, that is, two layers of cells in Fig. 4, and in agreement with Tables 5 and 6 let the numbers of cells in the two layers be $C_1 = 8$ and $C_2 = 12$, respectively. Let the total number of photons be $N_1 + N_2 = 20$ and let it be required to find how many photons (N_1) should be assigned to the cells C_1 and how many (N_2) to the cells C_2 in order to have as many arrangements as possible. If we are to solve the problem by trials, we may first put $N_1 = 20$, $N_2 = 0$. Using for the number of arrangements the fundamental formula [32], that is

$$W = (N + C - 1)!/[N!(C - 1)!] \ldots\ldots\ldots\ldots [32]$$

we find $W_1 = 27!/20!7!$ and $W_2 = 1$. This will give the total number of arrangements, $W_{12} = W_1 W_2$. Then we may take $N_1 = 19$, $N_2 = 1$, and again determine the value W_{12}. In this manner, we can find by trials the numbers N_1 and N_2 for which W_{12} is a maximum. Of course, in our problem it is not the number of photons, but the total energy that remains constant, but essentially the step-by-step method just outlined is equivalent to an analytical determination of max W_t, as described in Section 8. This is also the method by which Planck's formula has been deduced.

Now, in solving the same problem, suppose we concentrate our attention on formula [35], that is

$$V = C!/\Pi Z_r! \ldots\ldots\ldots\ldots [35]$$

instead of formula [32]. It will be remembered that in Tables 5 and 6 formula [35] is used in each horizontal line to compute the number of arrangements with a specified number of cells of each kind. For example, in Table 5, in the last line, we prescribe that six cells must have one photon each $(Z_1 = 6)$ and two cells three photons each $(Z_3 = 2)$. Formula [35] will show us that 28 such arrangements are possible, depending on which two cells are occupied by three photons each.

Proceeding now by trials, we first assign to each set of cells a certain number of photons, say $N_1 = 12$, $N_2 = 8$, and also prescribe the values of Z's in each set of cells. In other words, we take any line in Table 5 and any other line in Table 6, determine the values of V_1 and V_2, and compute the product $V_{12} = V_1 V_2$. This will give the total number of combinations with prescribed types of cells. Now we may pick out two other lines and again form the product V_{12}, etc. Finally, we succeed in locating by trials two lines for which the product V_{12} is a maximum. In Table 5 we have to take the fifth or the sixth line and in Table 6 the sixth line.

After this we try, for example, $N_1 = 11$ and $N_2 = 9$, and again determine max V_{12}. By proceeding in this manner, we ultimately find the values of N_1 and N_2 for which max V_{12} is greater than with any other combination of N_1 and N_2. These values of N_1 and N_2 we then take to be those for which the total number of arrangements W_{12} is also the maximum maximorum.

This method is equivalent to finding a maximum of expression [48] in section 9. The result, Eq. [68], is identical with that

obtained by the first method and given by Eq. [47]. We can therefore conclude that, within the accuracy of Stirling's formula, max W_t and max V_t are satisfied by the same numbers of photons assigned to each layer. This agrees with the statement previously made that with large numbers of photons per layer, the most probable distribution differs but little from the average distribution. This means that we may concentrate our attention beforehand on the most probable distribution in each layer, leaving others out of consideration. This is equivalent to the use of formula [48] in place of [39]. The relationship expressed by formula [30] may also help to see the connection between max W_t and max V_t.

It is only natural to expect that when a new mathematical theory appears, some physicists should attempt to generalize it and to show that the reasoning involved is but a specific case of a more general relationship. Some such attempts have been made since the appearance of Bose and Fermi statistics (3, 7, 19).

BIBLIOGRAPHY

1 "The New Quantum Mechanics," by G. Birtwistle, Cambridge University Press, London, 1928; chapter 28; also "The Quantum Theory of the Atom," by G. Birtwistle, Cambridge University Press, London, 1926, chapter 1.

2 "Planck's Gesetz und Lichtquantenhypothese," by S. N. Bose, *Zeit. für Physik*, vol. 26, 1924, p. 178; also "Wärmegleichgewicht im Strahlungsfeld bei Anwesenheit von Materie," by S. N. Bose, *Zeit. für Physik*, vol. 27, 1924, p. 384.

3 "La Statistique des Quanta de Lumière (photons)," by L. Brillouin, Comptes Rendus, vol. 184, 1927, p. 589.

4 "Ondes et Mouvements," by L. de Broglie, Gauthier-Villars et Cie, Paris, 1926, chapters 12 and 13.

5 "La Mécanique Ondulatoire," by L. de Broglie, Gauthier-Villars et Cie, Paris, 1928, chapter 1.

6 "Introduction to the Theory of Infinite Series," by T. J. I'A. Bromwich, The Macmillan Company, New York and London, 1926, p. 461.

7 "A Generalized Form of the New Statistics," by S. Chandrasekhar, *Physical Review*, vol. 34, 1929, p. 1204.

8 "An Introduction to Mathematical Probability," by J. L. Coolidge, Oxford University Press, New York and London, 1925, p. 38.

9 "Statistical Theories of Matter, Radiation and Electricity," by K. K. Darrow, *Physical Review Supplement*, vol. 1, 1929, p. 109. Also reprinted in *Bell System Technical Journal*, vol. 8, 1929, p. 694.

10 "General Forms of Statistical Mechanics With Special Reference to the Requirements of the New Quantum Mechanics," by R. H. Fowler, Proceedings of the Royal Society of London, vol. 113A, 1926–1927, p. 432.

11 "Statistical Mechanics," by R. H. Fowler, Cambridge University Press, London, 1929, chapter 2.

12 "Statistik von Systemen mit vielen Freiheitsgraden," by R. Fürth, Handbuch der Physik, vol. 4, 1929, p. 263; also "Die kinetische Theorie der Gase und Flüssigkeiten," by G. Jäger, Handbuch der Physik, vol. 9, 1926, p. 370.

13 "Dictionary of Applied Physics," edited by R. T. Glazebrook, The Macmillan Co., New York and London, 1923, pp. 541–572.

14 "A Course in Mathematical Analysis," by E. Goursat, translated by E. R. Hedrick, Ginn and Company, Boston, Mass., vol. 1, 1917, p. 290.

15 "Materiewellen und Quantenmechanik," by A. E. Haas, Akademische Verlagsgesellschaft, 1929, chapter 13. The book is also available in English.

16 "The Dynamical Theory of Gases," by J. H. Jeans, Cambridge University Press, London, 1925, chapters 16 and 17.

17 "Some Recent Developments of Statistical Mechanics," by J. E. Lennard-Jones, Proceedings of the Physical Society of London, vol. 40, 1928, page 320.

18 "Vorlesungen über die Theorie der Wärmestrahlung," by M. Planck, fifth edition, J. A. Barth, Leipzig, 1923, pp. 138 and 169.

19 "Black Radiation Regarded as Saturated Photon Vapor," by G. Polvani, *Il Nuovo Cimento*, vol. 6, 1929, p. 186.

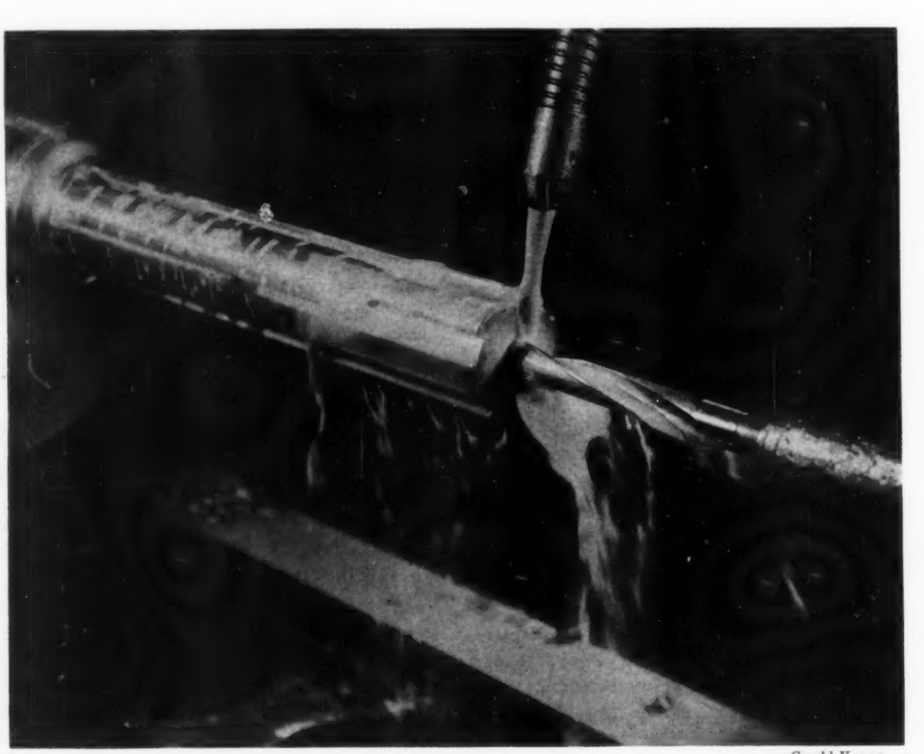
20 "Introduction to Modern Physics," by F. K. Richtmyer, McGraw-Hill Book Company, 1928, chapter 7.

21 "Bemerkungen über die Statistische Entropiedefinition beim idealen Gas," by E. Schroedinger, Akademie der Wissenschaften, Sitzungsberichte, 1925, p. 434.

22 "Statistical Mechanics With Applications to Physics and Chemistry," by R. C. Tolman, The Chemical Catalog Company, Inc., New York (American Chemical Society. Monograph series), 1927, chapter 4.

23 "Modern Analysis," by E. T. Whittaker and G. N. Watson, Cambridge University Press, London, 1927, chapter 6.

24 "Restricted Theory of Relativity in Terms of Hyperbolic Functions of Rapidities," by V. Karapetoff, *American Mathematical Monthly*, vol. 43, 1936, p. 70.



Gerald Young

DRILLNG SHAFT ON TURRET LATHE

EDUCATION *of the* ENGINEER

First Results of the Survey of the Status of the Engineering Profession Conducted by the U. S. Bureau of Labor Statistics

READERS of MECHANICAL ENGINEERING will recall having filled out early in 1935 a questionnaire on their professional experience and status, prepared by the United States Bureau of Labor Statistics, Dr. Isador Lubin, Commissioner, at the request and with the cooperation of the American Engineering Council. In the *Monthly Labor Review* for June, 1936, the first results of this survey of the engineering profession are presented in an article entitled, "Educational Qualifications in the Engineering Profession," prepared by Andrew Fraser, Jr., of the Bureau's Division of Wages, Hours, and Working Conditions. This is the first of a series of summary articles covering results of the survey, and through the courtesy of Dr. Lubin, a résumé of Mr. Fraser's article, and excerpts from it, are here presented.

GENERAL CONCLUSIONS

The general conclusions as to educational qualifications in the engineering profession are stated by Mr. Fraser as follows:

A first degree in engineering is now almost a prerequisite in order to obtain professional status and a position. Postgraduate work, however, is important in only a few of the professional classes. The tendency of engineers to transfer from the course of college specialization to other classes of work is negligible. These are a few of the facts developed in the survey of the engineering profession, which was undertaken by the Bureau of Labor Statistics in May, 1935, at the request of the American Engineering Council.

SCOPE AND METHOD

In order to make clear the purpose, scope, and methods of the survey, it is convenient to quote the following passages from Mr. Fraser's article:

The principal purpose of this survey was to determine how the engineers fared during the depression period. More specifically, the objectives were to determine the extent of unemployment, what kind of professional employment gave engineers the greatest protection against unemployment, where they found substitute employment, and their compensation between December 31, 1929, and December 31, 1934. However, to provide a comprehensive background for these data, the survey was extended to include the salient features of education and subsequent experience, so that the nature of the general trends affecting the profession could more readily be determined. Unquestionably, a knowledge of trends is of inestimable value to administrators of professional engineering education and to the practicing and prospective engineer.

The data were obtained through the medium of a mail questionnaire, requesting information, for the three periods ending December 31, 1929, 1932, and 1934, on: Present city and state residence; marital status and number of dependents; type of education; employment; unemployment; earnings; membership in engineering societies; method of obtaining employment, together with information on contract, patent, pension, and civil-service privileges; field of activity; functional classification; and professional class. A copy of this questionnaire was sent to each of 173,151 engineers.

The mailing list for the questionnaire was compiled for the Bureau through the cooperation of national, state, and local engineering societies, and additional names were obtained from 32 state boards of engineer examiners and the deans of 156 engineering schools. At the time the requests for names were issued, there were known to be in existence 80 national, 42 state, and 197 local societies, and of these, respectively, 73, 39, and 121 submitted names from their past and present membership rosters. Obviously, since the cooperating bodies embraced every phase of professional activity, the original mailing list, from which duplications were eliminated, can be accepted with little question as being adequate.

Of the 173,151 questionnaires sent out, 58,388, or 33.7 per cent, were returned with information; 5883, or 3.4 per cent, were returned as "not found;" and no replies were received from 108,880, or 62.9 per cent. The net number of usable returns was 52,589, or 30.4 per cent of the number of persons on the original mailing list, a most gratifying response, especially in view of the fact that no follow-up method was used.

Table 1 summarizes the results of the survey on the basis of the geographical distribution of the nine major professional classes into which the engineers replying to the questionnaire were grouped.

NATURE OF EDUCATIONAL DATA

Regarding the nature of the educational data sought and classified, Mr. Fraser says:

Since education is closely related to professional activity, information on this point was the first to be compiled for analysis.

At the outset, it should be remarked that no specific information was requested in this survey concerning curricula in education. The only questions asked were with respect to the particular type of education received, and these types embraced secondary school, noncollegiate technical school, university, or college, including nongraduate, graduate, and postgraduate work. In each case, the questionnaire called for the number of years of attendance, the name of the institution, the course taken (whether liberal arts, civil engineering, etc.), and the date of graduation. Nevertheless, as there is a close relation between

TABLE 1 GEOGRAPHICAL DISTRIBUTION OF THE NINE MAJOR PROFESSIONAL CLASSES OF ENGINEERS

		Geographical division									
Professional class	Total	District of Columbia	East South Central	Mountain	West South Central	South Atlantic	New England	West North Central	Pacific	East North Central	Middle Atlantic
United States	52589	948	1544	2434	2486	3920	4674	4978	5651	10977	14977
Agricultural	397	9	21	20	36	38	10	123	38	71	31
Architectural	538	10	8	20	22	29	44	107	30	139	129
Ceramic	388	3	11	2	5	22	10	38	26	169	102
Chemical	3512	37	107	108	213	291	369	296	179	878	1034
Civil	19891	450	707	1191	1082	1619	1631	2295	3099	3244	4523
Electrical	11443	195	286	385	489	856	1080	991	920	2412	3829
Industrial	1007	6	19	14	18	76	129	56	44	270	375
Mechanical	13226	197	320	285	548	898	1313	884	986	3343	4452
Mining and metallurgical	2187	41	65	409	73	91	88	188	329	401	502

TABLE 2 DISTRIBUTION OF THE NINE PROFESSIONAL CLASSES OF

		Professional class											
		Agricultural			Architectural			Ceramic			Chemical		
	Type of education	No.	Per cent of total	Per cent of professional class	No.	Per cent of total	Per cent of professional class	No.	Per cent of total	Per cent of professional class	No.	Per cent of total	Per cent of professional class
	Engineering graduates												
	Course same as professional class:												
1	First degree in engineering	201	82.4	50.6	338	94.2	62.8	294	90.2	75.8	2488	84.3	70.9
2	Engineering only	200	82.0	50.3	329	91.7	61.2	289	88.7	74.5	2385	80.8	68.0
3	Engineering, plus B.A. in liberal arts	1	0.4	0.3	9	2.5	1.6	4	1.2	1.0	89	3.0	2.5
4	Engineering, plus M.A. in liberal arts	...	...	...	...	...	...	1	0.3	0.3	6	0.2	0.2
5	Engineering, plus Ph.D. in liberal arts	...	...	...	...	...	...	...	...	...	8	0.3	0.2
6	Master's degree in engineering	42	17.2	10.5	21	5.8	3.9	30	9.2	7.7	363	12.3	10.4
7	Engineering only	42	17.2	10.5	21	5.8	3.9	30	9.2	7.7	360	12.2	10.3
8	Engineering, plus B.A. in liberal arts	...	...	...	...	...	...	...	...	...	3	0.1	0.1
9	Doctor's degree in engineering	1	0.4	0.3	...	...	...	2	0.6	0.5	100	3.4	2.8
10	Total	244	100.0	61.4	359	100.0	66.7	326	100.0	84.0	2951	100.0	84.1
	Course different from professional class:												
11	First degree in engineering	97	87.4	24.5	38	97.5	7.1	15	75.0	3.9	121	84.0	3.5
12	Engineering only	92	82.9	23.2	38	97.5	7.1	14	70.0	3.6	117	81.2	3.4
13	Engineering, plus B.A. in liberal arts	4	3.6	1.0	...	...	...	1	5.0	0.3	4	2.8	0.1
14	Engineering, plus M.A. in liberal arts	1	0.9	0.3	...	...	...	...	...	...	...	...	...
15	Engineering, plus Ph.D. in liberal arts	...	...	...	...	...	...	...	...	...	...	...	...
16	Master's degree in engineering	14	12.6	3.5	1	2.5	0.2	5	25.0	1.3	19	13.2	0.5
17	Engineering only	14	12.6	3.5	1	2.5	0.2	5	25.0	1.3	18	12.5	0.5
18	Engineering, plus B.A. in liberal arts	...	...	...	...	...	...	...	...	...	1	0.7	...
19	Doctor's degree in engineering	...	...	...	...	...	...	...	...	...	4	2.8	0.1
20	Total	111	100.0	28.0	39	100.0	7.3	20	100.0	5.2	144	100.0	4.1
	Other engineers												
21	Nonengineering graduates	13	...	3.2	36	...	6.7	16	..	4.1	212	...	.0
22	Engineering graduates (with other degrees) in nonengineering fields	1	...	0.3	...	...	...	...	...	...	23	...	0.7
23	College engineering course, unfinished	17	...	4.3	67	...	12.5	16	...	4.1	154	...	4.3
24	Noncollegiate technical-school engineers	5	...	1.3	26	...	4.8	5	...	1.3	20	...	0.6
25	Secondary-school engineers	6	...	1.5	6	...	1.1	5	...	1.3	3	...	0.1
26	Total	42	...	10.6	135	...	25.1	42	...	10.8	412	...	11.7
27	Total, not reporting	...	...	...	5	...	0.9	...	...	...	5	...	0.1
28	Grand total	397	...	100.0	538	...	100.0	388	...	100.0	3512	...	100.0

curricula and type of education, there is some justification for using the latter as a basis for analysis, especially since by so doing there is the decided advantage of obtaining a broad picture of the situation, which of course facilitates the subsequent analyses.

With more particular reference to trends, this article is concerned with (1) the prevalence of first degrees in engineering, (2) the extent of postgraduate work, (3) the tendency of engineers to transfer from the course of specialization to other professional fields, (4) the nature of the distribution as between all graduates and nongraduates of "other engineers," and (5) the general relation of education to fields of activity and functional classification.

UNIVERSITY TRAINING IN ENGINEERING

The distribution of the nine professional classes by type of education in the country as a whole, as of 1934, is shown in Table 2. Engineers reporting were divided into two groups, one including engineering graduates, i.e., those who reported having obtained an engineering degree from a college or university, and other engineers, i.e., all those who received a secondary-school, noncollegiate, nongraduate, or nonengineering education.

Engineering graduates, Mr. Fraser explains, are in turn divided into two groups, "graduates whose professional class is the same as the college course in which they specialized and those whose professional class is different from the specialized college course. From this arrangement," he continues, "the importance of first degrees and of postgraduate work in engineering may be determined, first, with reference to the graduate group as a whole, and second, as related to the grand total reporting in each professional class." It is clear from the tabulation that in each professional class as a whole the number of men with first degrees only strongly predominates.

Graduate study in engineering does not appear to be of any considerable importance as a prerequisite to practice in engineering. (This fact was also brought out in the studies made by The American Society of Mechanical Engineers in its survey of the 1930 earnings of mechanical engineers.[1])

As the figures show, of the 52,589 engineers reporting, only 4413, or 8.4 per cent, were graduates in engineering who were practicing in another branch of the profession than the one for which they had qualified in college. "Hence," Mr. Fraser observes, "considering the fact that some transfers in professional work are inevitable and that these are largely concentrated in but few professional classes, it can only be concluded that this tendency is an insignificant factor. . . . . In other words, it may be concluded that by and large the respective curricula [of engineering colleges] meet the needs of the profession."

OTHER ENGINEERS

From a section of Mr. Fraser's article dealing with "other engineers," the following excerpts are quoted:

> In the group of "other engineers," 1304, or 2.5 per cent of the nonengineering graduates reporting, had degrees in the liberal arts. This is not a very large proportion but it is interesting to note that this group has remained fairly constant since as far back as 1889. It is difficult to explain how such a group is able to attain professional status without formal education in the engineering field, although this

[1] See MECHANICAL ENGINEERING, vol. 53, 1932, pp. 651–656, 817–823, and 876–882.

ENGINEERS, IN THE UNITED STATES, 1934, BY TYPE OF EDUCATION

Professional class—continued																		
Civil			Electrical			Industrial			Mechanical			Mining and metallurgical			Total			
No.	Per cent of total	Per cent of professional class	No.	Per cent of total	Per cent of professional class	No.	Per cent of total	Per cent of professional class	No.	Per cent of total	Per cent of professional class	No.	Per cent of total	Per cent of professional class	No.	Per cent of total	Per cent of professional class	
12302	94.6	61.9	8460	91.7	73.9	403	95.9	40.0	8390	94.1	63.4	1366	89.4	62.5	34242	92.6	65.1	1
11884	91.3	59.8	8165	88.4	71.4	389	92.6	38.6	8174	91.7	61.9	1283	84.0	58.8	33098	89.5	62.9	2
376	2.9	1.9	245	2.7	2.1	13	3.1	1.3	197	2.3	1.4	66	4.3	3.0	1000	2.7	1.9	3
33	0.3	0.2	26	0.3	0.2	1	0.2	0.1	14	0.1	0.1	5	0.3	0.2	86	0.2	0.2	4
9	0.1	...	24	0.3	0.2	...	...	...	5	...	...	12	0.8	0.5	58	0.2	0.1	5
680	5.2	3.4	699	7.6	6.1	15	3.7	1.5	483	5.4	3.7	144	9.4	6.5	2477	6.7	4.7	6
672	5.1	3.4	690	7.5	6.0	13	3.1	1.3	479	5.4	3.7	141	9.2	6.4	2448	6.6	4.6	7
8	0.1	...	9	0.1	0.1	2	0.5	0.2	4	...	...	3	0.2	0.1	29	0.1	0.1	8
22	0.2	0.1	63	0.7	0.6	2	0.5	0.2	42	0.5	0.3	18	1.2	0.8	250	0.7	0.5	9
13004	100.0	65.4	9222	100.0	80.6	420	100.0	41.7	8915	100.0	67.4	1528	100.0	69.8	36969	100.0	70.3	10
1572	94.9	7.8	333	92.0	3.0	343	95.0	34.0	1356	94.1	10.3	234	84.1	10.7	4109	93.1	7.8	11
1521	91.7	7.6	322	88.9	2.9	332	91.9	32.9	1309	90.9	10.0	218	78.4	10.0	3963	89.8	7.6	12
49	3.0	0.2	10	2.8	0.1	10	2.8	1.0	38	2.6	0.3	12	4.3	0.5	128	2.9	0.2	13
1	0.1	...	...	...	...	...	1.3	0.1	6	0.4	...	2	0.7	0.1	11	0.2	...	14
1	0.1	...	1	0.3	...	...	...	...	3	0.2	...	2	0.7	0.1	7	0.2	...	15
75	4.5	0.4	25	6.9	0.2	15	4.2	1.5	79	5.5	0.6	31	11.2	1.4	264	6.0	0.5	16
73	4.4	0.4	24	6.6	0.2	15	4.2	1.5	75	5.2	0.6	31	11.2	1.4	256	5.8	0.5	17
2	0.1	...	1	0.3	...	...	...	...	4	0.3	...	...	...	...	8	0.2	...	18
10	0.6	0.1	4	1.1	...	3	0.8	0.3	6	0.4	...	13	4.7	0.6	40	0.9	0.1	19
1657	100.0	8.3	362	100.0	3.2	361	100.0	35.8	1441	100.0	10.9	278	100.0	12.7	4413	100.0	8.4	20
457	...	2.3	206	...	1.8	33	...	3.3	240	...	1.8	91	...	4.2	1304	...	2.5	21
149	...	0.7	119	...	1.0	23	...	2.3	174	...	1.3	9	...	0.4	498	...	0.9	22
2950	...	14.8	862	...	7.6	97	...	9.6	1299	...	9.9	189	...	8.7	5651	...	10.8	23
1124	...	5.7	517	...	4.5	52	...	5.2	879	...	6.7	55	...	2.5	2683	...	5.1	24
511	...	2.6	140	...	1.2	18	...	1.8	245	...	1.8	33	...	1.5	967	...	1.8	25
5191	...	26.1	1844	...	16.1	223	...	22.2	2837	...	21.5	377	...	17.3	11103	...	21.1	26
39	...	0.2	15	...	0.1	3	...	0.3	33	...	0.2	4	...	0.2	104	...	0.2	27
19891	...	100.0	11443	...	100.0	1007	...	100.0	13226	...	100.0	2187	...	100.0	52589	...	100.0	28

is possible in some instances, such as chemical, ceramic, mining and metallurgical, and architectural engineering. Nevertheless, it can be safely concluded that since graduates of academic courses have been in engineering fields over a long period, the probability is that they will continue to remain a factor in the profession.

Only 498 (0.9 per cent of the grand total) engineering graduates were reported as with further study in nonengineering fields. These persons had originally graduated in engineering, but later they swung into other fields of study, such as economics, business administration, law, etc. The small number found in this class is a substantiation of the fact that there is little transfer of occupation not only within the profession but also to preparation for professional work in fields other than engineering.

Engineering educators have for many years been aware that the "mortality" (i.e., the proportion dropping out before completion of course) among engineering students is very high, this having been disclosed by many previous studies. The number covered by the present survey who reported that they did not finish the engineering course in college was 5651, or 10.8 per cent of the total.

Noncollegiate technical-school engineers numbered 2683 or 5.1 per cent of the grand total reporting.

Of 967 engineers reported as having had only a secondary-school education, the largest numbers were civil and mechanical engineers, the total of these being 756, or 78.2 per cent of the 967 reporting.

In order to determine more clearly the nature of the general trends with regard to the "other engineers" group, an analysis of the distribution as between all graduates and the nongraduates of the "other engineers" is necessary. Of the engineers classified as "recent" since they entered the profession after the 1930 census, 18,451, or 98.48 per cent, reported as having graduated between 1930 and 1934. Contrasted to this group, there are only 286, or 1.52 per cent, "other engineers," i.e., those who did not report graduation but were born within the period of 1910–15. On the other hand, there are 33,852 older engineers of whom 24,837, or 73.4 per cent, reported graduation up to and including 1929. This may be compared, however, with 9015 "other engineers" (26.57 per cent) who did not report graduation but were born within the period ending with 1909. The enormous decrease in the ratio of "other engineers" to graduates as between the older and recent engineers is the best evidence that graduation in engineering is almost a necessity for entry into the profession.

The demand for graduation as a qualification for professional status in engineering is not a recent development; it is a growing trend that may be traced back for more than 50 years. This is clearly brought out in Table 3, which presents data for the three classes of nongraduates of the "other engineers," showing in each case their distribution by year of birth as of 1934. . . . The small percentage of recent engineers, compared to the large percentage of old engineers, in each of these three groups of nongraduates again emphasizes the fact that the chances of attaining professional status without a college degree have markedly decreased.

FIELDS AND FUNCTIONS

Table 4, which should be compared with similar data from a recent survey of mechanical engineers,[2] shows an analysis of the fields of activity and the functional classification of engineers. Mr. Fraser says, "only those engineers who had an engineering job as of December 31, 1934, were interrogated on these points, this explains the two totals in Table 4, given as 'reporting' and 'not reporting' the field of activity and functional classification in the nine professional classes." He continues:

[2] See "The A.S.M.E. Member's Job," MECHANICAL ENGINEERING, vol. 58, March, 1936, pp. 162–164.

TABLE 3 DISTRIBUTION OF NONGRADUATES AMONG "OTHER ENGINEERS," BY YEAR OF BIRTH, UNITED STATES, 1934

Education	Born in period	Total: Number	Total: per cent	Professional class: Agricultural	Architectural	Ceramic	Chemical	Civil	Electrical	Industrial	Mechanical	Mining and metallurgical
Nongraduate engineers:												
College engineering course unfinished	1910–14	218	3.9	...	2	1	15	94	49	5	39	13
	1905–09	738	13.1	...	12	4	32	352	153	16	150	19
	1900–04	914	16.2	3	9	3	21	443	198	13	211	13
	1895–99	899	15.9	3	6	3	22	435	157	29	215	29
	1890–94	790	14.0	7	13	2	17	412	101	13	202	23
	1885–89	790	14.0	1	13	3	16	450	88	11	176	32
	1880–84	596	10.5	3	5	...	14	341	57	6	144	26
	1875–79	348	6.1	...	2	...	7	212	34	2	76	15
	1874[a]	358	6.3	...	5	...	10	211	25	2	86	19
Total	.....	5651	100.0	17	67	16	154	2950	862	97	1299	189
Noncollegiate technical school	1910–14	52	1.9	...	...	...	1	14	22	...	13	2
	1905–09	224	8.3	...	2	2	2	88	84	3	43	...
	1900–04	360	13.4	...	3	...	3	144	99	8	100	3
	1895–99	375	14.0	1	3	1	2	156	84	7	113	8
	1890–94	476	17.8	1	4	...	6	201	68	14	175	7
	1885–89	452	16.8	1	6	...	3	186	70	6	169	11
	1880–84	358	13.4	...	4	...	1	169	49	8	119	8
	1875–79	199	7.4	1	1	2	2	84	28	6	72	3
	1874[a]	187	7.0	1	3	...	...	82	13	...	75	13
Total	.....	2683	100.0	5	26	5	20	1124	517	52	879	55
Secondary school	1910–14	16	1.7	...	...	1	...	5	7	...	2	1
	1905–09	88	9.1	...	...	...	2	49	25	...	12	...
	1900–04	110	11.4	1	...	...	1	57	24	...	25	2
	1895–99	128	13.2	...	...	4	...	58	21	3	36	6
	1890–94	152	15.7	2	1	...	...	78	17	4	45	5
	1885–89	165	17.1	3	2	...	...	86	19	7	43	5
	1880–84	108	11.1	...	...	...	...	56	13	1	35	3
	1875–79	83	8.6	...	...	...	...	50	8	1	20	4
	1874[a]	117	12.1	...	3	...	...	72	6	2	27	7
Total	.....	967	100.0	6	6	5	3	511	140	18	245	33
Total nongraduate engineers	.....	9301	17.7	28	99	26	177	4585	1519	167	2423	277
Graduate engineers	.....	43288	82.3	369	439	362	3335	15306	9924	840	10803	1910
Grand total	.....	52589	100.0	397	538	388	3512	19891	11443	1007	13226	2187

[a] Or earlier.

Strictly speaking, the fields of activity and functional classifications may be more simply described as the branches of engineering engaged in and the functions performed in those branches. . . .

AGRICULTURAL ENGINEERS

Of the agricultural engineers reported as employed on December 31, 1934, no less than 51.5 per cent were in Government work, probably due to the great demand for engineers in such work as soil erosion, irrigation, etc. Personal service absorbed 27.7 per cent of the total, the remaining agricultural engineers being distributed in construction, manufacturing, public utilities, and private utilities, and private agriculture and forestry. . .

ARCHITECTURAL ENGINEERS

The architectural engineers also found Government work the best recent possibility for employment, with 40.3 per cent so employed; 39.4 per cent were in private construction, and only 10 per cent in manufacturing, the remainder being in public utilities, personal service, and extractive industries. . .

CERAMIC ENGINEERS

Ceramic and chemical engineers are very similar with regard to their distributions in both the fields of activity and functional classifications. In each case, the largest percentage is to be noted in manufacturing, the figures being 86.8 for ceramic and 72 for chemical engineering. The number engaged in Government work formed only 6.7 per cent of the chemical and 2.6 per cent of the ceramic engineers. . .

CIVIL ENGINEERS

Referring to civil engineers, the percentage of those employed by Governmental agencies is no less than 63.3, the next highest being those in private organizations rendering engineering service, with only 15.4 per cent. This unusually large relative number in Government work is explained primarily by the almost complete cessation, during the period immediately preceding the survey, of civil engineering opportunities in the normal fields of activity other than Government. In the distribution of the civil engineers with regard to functional classifications, construction leads with 45.7 per cent, followed by design and research with 21.8 per cent, and operation with 12.5 per cent—a total of 90 per cent, in these three classifications.

ELECTRICAL ENGINEERS

As anticipated, the percentage of electrical engineers in public utilities is high, being 39.7, but it is also interesting to note that as many as 33.7 per cent reported manufacturing as their field of activity. No less than 9.8 per cent were in Government work, and 9.1 per cent were in personal service. Again (as for civil engineers) the first three functional classifications cover 72 per cent of all reporting, although the order is operation with 34.1 per cent, design and research with 27.9 per cent, and construction with 10.8 per cent.

INDUSTRIAL AND MECHANICAL ENGINEERS

Industrial and mechanical engineers are largely in manufacturing, the former having 66.8 per cent and the latter 52.2 per cent of the total. In the case of industrial engineers, the next highest percentages were 8.8 in public utilities and 8.1 in personal service, and for mechanical engineers 9.9 in personal service, 8.7 in construction, and 8.4 in public utilities. With reference to the distribution, by functional classification, of the 682 industrial engineers reporting, 33.6 per cent were in operation, 27.4 per cent were in general administration and management, and 13.5 per cent were in design and research. Of the 8764 mechanical engineers, the highest percentage, 33.8, was in design and research, while 25.9 per cent were in operation, 9.6 in construction, and 8.8 in administration and management.

TABLE 4 DISTRIBUTION OF ENGINEERS BY ZONE OF INTEREST AND FUNCTION, UNITED STATES, 1934

Classification	Professional class: Agricultural Number	Agricultural Per cent	Architectural Number	Architectural Per cent	Ceramic Number	Ceramic Per cent	Chemical Number	Chemical Per cent	Civil Number	Civil Per cent
Field of activity										
Construction	29	9.4	91	39.4	5	1.9	32	1.4	2148	15.4
Extractive industries	...	...	2	0.9	8	3.0	147	6.7	447	3.2
Public utilities	13	4.3	11	4.7	1	0.4	104	4.7	484	3.5
Transportation	...	...	...	...	...	...	18	0.8	517	3.7
Manufacturing	21	6.8	23	10.0	231	86.8	1592	72.0	705	5.1
Personal service	85	27.7	11	4.7	14	5.3	171	7.7	808	5.8
Agriculture and forestry	1	0.3	...	...	...	...	...	...	...	...
Government work[1]	158	51.5	93	40.3	7	2.6	148	6.7	8812	63.3
Total	307	100.0	231	100.0	266	100.0	2212	100.0	13921	100.0
Total not reporting	90	...	307	...	122	...	1300	...	5970	...
Functional classification										
Design and research	69	22.5	72	31.2	77	28.9	727	32.9	3030	21.8
Construction	85	27.7	102	44.1	9	3.4	48	2.1	6368	45.7
Operation	22	7.1	13	5.7	138	51.9	1051	47.5	1741	12.5
Consulting[2]	34	11.1	17	7.3	8	3.0	95	4.3	874	6.3
Teaching	62	20.2	9	3.9	11	4.2	128	5.8	553	4.0
Sales	12	3.9	7	3.0	8	3.0	67	3.1	175	1.2
General administration and management	23	7.5	11	4.8	15	5.6	96	4.3	1180	8.5
Total	307	100.0	231	100.0	266	100.0	2212	100.0	13921	100.0
Total not reporting	90	...	307	...	122	...	1300	...	5970	...

Classification	Professional class: Electrical Number	Electrical Per cent	Industrial Number	Industrial Per cent	Mechanical Number	Mechanical Per cent	Mining and metal Number	Mining and metal Per cent	Total Number	Total Per cent
Field of activity										
Construction	184	2.8	35	5.1	762	8.7	22	1.5	3308	9.6
Extractive industries	126	1.9	25	3.7	328	3.7	684	47.3	1767	5.1
Public utilities	2634	39.7	60	8.8	734	8.4	19	1.3	4060	11.8
Transportation	199	3.0	19	2.8	429	4.9	4	0.2	1186	3.5
Manufacturing	2231	33.7	456	66.8	4841	55.2	399	27.7	10499	30.4
Personal service	602	9.1	55	8.1	866	9.9	160	11.0	2772	8.1
Agriculture and forestry	...	...	...	...	1	([3])	...	...	2	([3])
Government work[1]	650	9.8	32	4.7	803	9.2	160	11.0	10863	31.5
Total	6626	100.0	682	100.0	8764	100.0	1448	100.0	34457	100.0
Total not reporting	4817	...	325	...	4462	...	739	...	18132	...
Functional classification										
Design and research	1846	27.9	92	13.5	2960	33.8	281	19.4	9154	26.6
Construction	717	10.8	42	6.1	841	9.6	97	6.7	8309	24.1
Operation	2261	34.1	229	33.6	2271	25.9	629	43.4	8355	24.2
Consulting[2]	423	6.4	67	9.8	507	5.8	161	11.2	2186	6.4
Teaching	487	7.3	24	3.6	635	7.2	127	8.7	2036	5.9
Sales	434	6.6	41	6.0	777	8.9	28	2.0	1549	4.5
General administration and management	458	6.9	187	27.4	773	8.8	125	8.6	2868	8.3
Total	6626	100.0	682	100.0	8764	100.0	1448	100.0	34457	100.0
Total not reporting	4817	...	325	...	4462	...	739	...	18132	...

[1] Includes federal, state, county, and municipal.
[2] Includes independent consultants and employees of consulting firms.
[3] Less than 1/10 of 1 per cent.

MINING AND METALLURGICAL ENGINEERS

Naturally, the highest percentage of mining and metallurgical engineers is in extractive industries, where 47.3 per cent were employed, although it is interesting to note that no less than 27.7 per cent reported manufacturing as their field of activity. The next two highest were 11 per cent each for personal service and Government work. As for the distribution by functional classification, the highest percentage appears in operation with 43.4, followed by design and research with 19.4. However, it will be seen that there is some importance attached to consulting as far as this professional class is concerned, as 11.2 per cent report this as their functional classification.

GENERAL DISTRIBUTION

When all the engineers reporting the field of activity are considered, the order of distribution is as follows: 30.4 per cent in manufacturing, 31.5 per cent in Government work, 11.8 per cent in public utilities, 9.6 per cent in construction, 8.1 per cent in personal services, and 5.1 per cent in extractive industries. For functional classification, design and research is first with 26.6 per cent, operation with 24.2 per cent, construction with 24.1 per cent, general administration and management with 8.3 per cent, consulting with 6.4 per cent, teaching with 5.9 per cent, and sales with 4.5 per cent.

IMPORT OF ANALYSIS

The import of this analysis is that there are certain well-defined fields of activity for each of the professional classes. In the case of agricultural and civil engineers it is obviously Government work. Architectural engineers are fairly well divided between construction and Government work; ceramic, chemical, industrial, and mechanical engineers are largely concentrated in manufacturing; electrical engineers are found mostly in public utilities and manufacturing; and mining and metallurgical engineers appear mostly in the extractive, industrial, and manufacturing zones. For each of the professional classes the outstanding functional classification are design and research, construction, and operation.

Other results of the Bureau of Labor Statistics study of the engineering profession are to be made public at a later day and will be reported in MECHANICAL ENGINEERING as they become available.

MACHINE INTERFERENCE

Two Solutions of Problem Raised by Multiple Machine Units

THE two papers published under this title are based on manuscripts contributed by the Management Division and presented at the Annual Meeting, December 3–7, 1934, of The American Society of Mechanical Engineers. At the request of the Division the authors condensed their original manuscripts for publication and a statement throwing more light on the fundamental derivation of the formulas presented by Messrs. Wright and Duvall was solicited from Harold A. Freeman. These independent contributions are properly credited to the three authors.—EDITOR.

I—BY WILMER R. WRIGHT

STEVENSON, JORDAN & HARRISON

IN ESTABLISHING time standards for multiple-unit machines, one of the most difficult problems that confronts the time-study engineer is the determination of interference time, i.e., the time each machine unit is "down" awaiting attention while the operator is busy giving attention to some other machine unit. Frequently, time-study engineers have spent considerable time determining accurately the machine running time and attention time for a given job, only to make a "wild" guess as to the interference. Others have spent days taking complete production-time studies of the units and measuring accurately this interference time, only to realize that the performance level was not standard and therefore the interference percentage was probably in error.

Since machine interference is a matter of chance, it was believed that a general formula could be developed for it by use of the mathematical theory of probability. The advantages of having such a formula were indeed great. First, it would save a large part of the time required to set standards for multiple-unit machines because it would eliminate the necessity of taking and analyzing long production-time studies. Second, it would result in much more accurate time standards in that the errors due to variation in conditions of the work during the study could be eliminated. Third, it would make it possible to set up element standards and formulas for a given class of machines which would be entirely general. Without such a general formula, standards may safely cover only the machine assignments and conditions for which interference studies are actually made. Finally, it would make it possible to compute in advance of installation the most economical number of machine units to assign to each operator from the standpoint of labor and machine costs.

In view of all the advantages of such a formula, it was decided to allot several hundred dollars for work on this problem. As a first step, an investigation was made to determine what work had already been done along this line. It was found that Thornton C. Fry, of the Bell Telephone Laboratories, had solved a problem in congestion of telephone lines, the conditions of which were nearly identical to the machine-interference problem. Dr. Fry's solution was therefore converted into terms of machine interference, as follows:

$$I = 50\left[\sqrt{(1+X-N)^2+2N}-(1+X-N)\right]$$

where I = interference in percentage of attention time
X = ratio of machine running time to attention time
N = number of units assigned to one operator.

It can be seen that this formula is so simple that it can be applied by any one having a knowledge of algebra. The formula was checked with the analysis of more than eleven hundred hours of actual shop observations during which interference had been measured and recorded. These studies covered the operation of eight entirely different types of machines and were therefore considered entirely general.

It was found that the formula checked accurately with these actual shop studies for assignments of six or more units per operator, but did not agree when the assignment was less than six. It is an interesting fact that the first check of this formula was made with data for a six-unit assignment. If this check had been made with data for a four-unit assignment, the formula would probably have been discarded as not applicable to the machine-interference problem. The discrepancy between the formula and actual performance data for small assignments was due primarily to Dr. Fry's assumption concerning the distribution of "calls." This assumption resulted in an increasing divergence as the assignments became smaller.

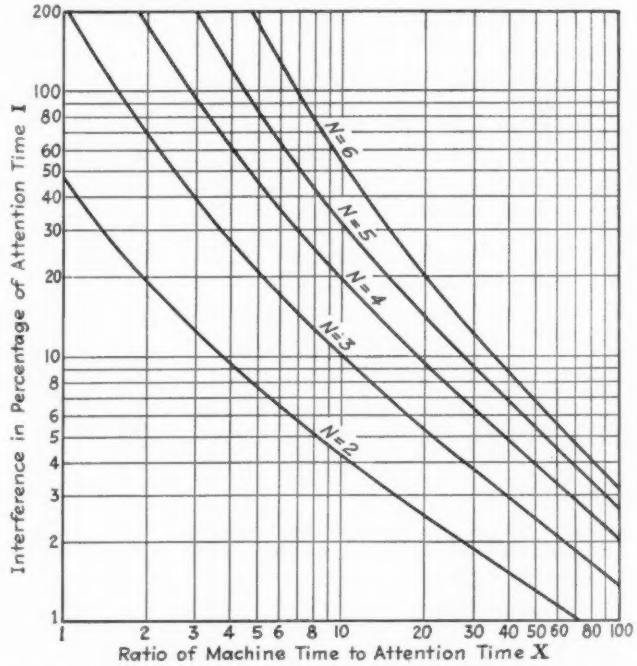


FIG. 1 INTERFERENCE IN PERCENTAGE OF ATTENTION TIME WHEN NUMBER OF UNITS ASSIGNED TO ONE OPERATOR IS SIX OR LESS

A set of empirical curves, Fig. 1, was therefore developed from the actual performance data for assignments of from two to six units With this supplement to the formula, interference values may be determined for any assignment or any multiple-unit job by simply determining the ratio of machine running time to attention time for each unit.

As a further application of this interference study a formula was developed for determining the economic number of units that should be assigned to one operator. This is the number at which the decreased labor cost due to increasing the assign-

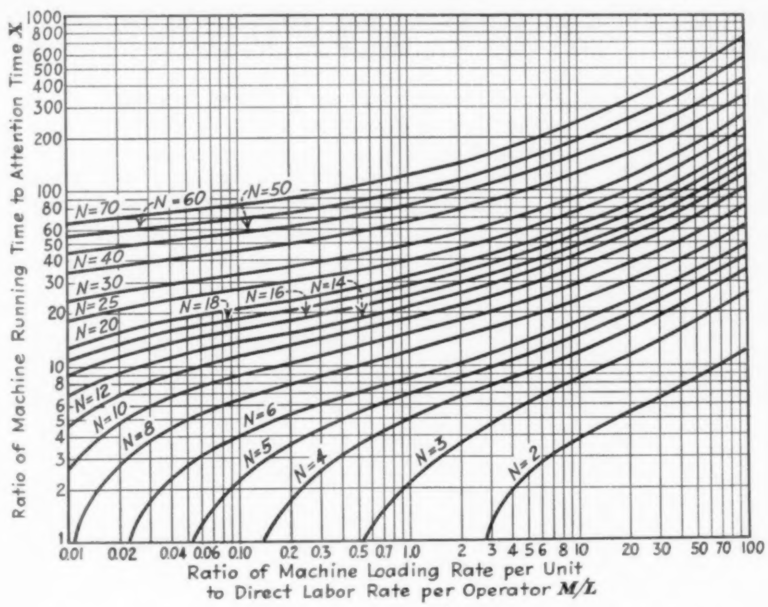


FIG. 2 CHART FOR DETERMINING ECONOMIC ASSIGNMENT OF MACHINES

ment is entirely offset by increased machine cost. In other words, an increase in the number of units tended by one operator will increase the output per operator but will decrease the output per machine because of increased interference. The economic-assignment formula was determined by setting up an equation for total cost in terms of the number of units assigned to one operator and setting the first derivative of this equation equal to zero. Thus, conditions which satisfy this equation will give the minimum cost. The complete mathematical development of this formula is given in a later section of this paper. To facilitate the application of this formula, the curves in Fig. 2 were developed from which the economic assignment for any given set of conditions can be taken directly.

EXAMPLE

As an example of the method of applying the formulas, assume the following conditions:

A new type of winding unit has been developed and in determining the floor layout it is necessary to know the number of units to be assigned to each operator. A set of time studies is therefore made of several individual machine units and it is found that

Machine running time = 25 min per lb
Attention time = 1 min per lb
Cost chargeable to machine = \$0.10 per unit per hr
Direct labor cost = \$0.40 per operator per hr.

Then
$$X = 25/1 = 25$$
$$M/L = 0.10/0.40 = 0.25$$

Referring to Fig. 2, the lines $X = 25$ and $M/L = 0.25$ intersect at $N = 20$. This is the economic number of units to be assigned to each operator.

To determine the standard time for this job which will apply when the final setup of 20 machines per operator is effective, all else that is needed is the interference time. This can be determined directly from the interference formula.[1] Substituting the above values

$$I = 50\left[\sqrt{(1+25-20)^2 + 2\,(20)} - (1+25-20)\right]$$
= 136 per cent of the attention time or 1.36 min per lb.

Thus the correct assignment and the standard time is determined before the machines are set in final position.

The important question to the average reader is: "Can these formulas be applied to my particular job?" In the first place he must be assured that these interference values are accurate. The most practical way to demonstrate this point is to check them against actual shop observations. He should then have some member of his organization who is mathematically inclined study the complete development of the formulas so that he can judge whether the assumptions made are permissible for his particular problem.

Checks that have been made to date indicate that these formulas are universally applicable. They have been applied in four entirely different industries and have given accurate results in each. The time required for setting up time standards for multiple-unit jobs has been greatly reduced. The consistency of earnings on these standards indicates a considerable improvement in accuracy. It has been possible to set up more universally applicable element standards. In addition a number of adjustments have been made in machine assignments which have resulted in important reductions in total cost.

DEVELOPMENT OF INTERFERENCE FORMULA

The general formula for interference was converted from the solution of a similar problem which was made by T. C. Fry in his book entitled "Probability and its Engineering Uses." The principal conditions assumed in the development of Dr. Fry's formula are as follows:

(1) A group of telephone lines having access to one common trunk line are handled in such a manner that if a call requiring the use of this trunk line originates on one line while a call on another line is already making use of the trunk, the second call will be delayed until the first call is finished and will then be given access to the trunk line.

(2) All telephone calls are of equal length.

(3) The calls which are assigned to the group of channels are distributed individually and collectively at random.

The first condition is obviously identical with the conditions of the machine-interference problem.

The second condition does not apply accurately, but it was realized that if the assumption would give satisfactory results for telephone delay, it should apply to machine interference.

The third condition is not true for small numbers of machines or for high percentages of attention time. It was found, however, that when the number of machine units assigned to one operator is equal to or greater than six, the actual occurrences within the practical range of operation approximate this assumption closely.

Dr. Fry's formula was converted into terms of the machine-interference problem by the following mathematical steps:

Let a = aggregate work time or attention time per machine unit per day. (This does not include spare-time operations performed while all units are "running.")
m = aggregate machine running time per machine unit per day
i = aggregate interference time per machine unit per day
N = number of machine units assigned to one operator
T = length of each attention time

[1] If N were less than six, the chart shown in Fig. 1 would be used.

$\bar{I}$ = average interference per attention time (corresponds to $E(T)$ = average delay per call in Dr. Fry's solution)
E = fraction of time operator is busy
I = total interference expressed as a percentage of total attention time
X = ratio of machine time to attention time = m/a. (This also equals the ratio of the machine time per unit of output to the attention time per unit of output.)

Then from Dr. Fry's formula [198], "Probability and Its Engineering Uses," page 378

$$E(T) = \frac{T}{2}\,\frac{E}{1-E} = \bar{I} \quad \ldots\ldots\ldots\ldots\ldots [1]$$

But by definition

$$E = \frac{Na}{a+m+i} \quad \ldots\ldots\ldots\ldots\ldots [2]$$

$$\bar{I} = \frac{TNa}{2}\,\frac{1}{a+m+i-Na} \quad \ldots\ldots\ldots\ldots [3]$$

Aggregate interference i equals the number of work times multiplied by the average interference per work time $\bar{I}$. The number of work times equals the aggregate work time a divided by the length of each work time T. Thus

$$i = (a/T)\,\bar{I} \quad [4]$$

Substituting in [3]

$$\bar{I} = \frac{TNa}{2}\,\frac{1}{a+m+(a/T)\,\bar{I}-Na} \quad \ldots\ldots\ldots [5]$$

Solving for $\bar{I}$ by use of the quadratic formula

$$\bar{I} = \frac{T}{2a}\left[\sqrt{(a+m-Na)^2+2\,Na^2}-(a+m-Na)\right] \ldots [6]$$

It is desired to present this in a formula with aggregate interference i in percentage of aggregate attention time a as the dependent variable, and the ratio of aggregate machine time m to aggregate attention time a as the independent variable, that is

$$I = (i/a)\,100 \quad \ldots\ldots\ldots\ldots\ldots [7]$$

$$X = m/a \quad \ldots\ldots\ldots\ldots\ldots [8]$$

Substituting [4] for i in [7]

$$I = (\bar{I}/T)\,100 \quad \ldots\ldots\ldots\ldots\ldots [9]$$

Substituting [6] in [9]

$$I = \frac{100}{T}\,\frac{T}{2a}\left[\sqrt{(a+m-Na)^2+2Na^2}-(a+m-Na)\right] \,.\, [10]$$

Eliminating m and a by use of [8] in [10]

$$I = 50\left[\sqrt{(1+X-N)^2+2N}-(1+X-N)\right] \ldots [11]$$

DEVELOPMENT OF ECONOMIC-ASSIGNMENT FORMULA

The following are the mathematical steps involved in developing the formula for economic assignments:

Let C = cost per unit of output in dollars
A = attention time per unit of output in hours. (It is assumed that this remains constant regardless of the number of units assigned to one operator. In other words, it is assumed that fatigue does not enter into the problem.)
B = machine time per unit of output in hours
I = interference in percentage of attention time A
L = direct labor cost per operator per hour. (It is assumed that the operator's hourly rate remains constant regardless of the number of units assigned.)
N = number of machine units assigned to one operator
M = machine cost per machine unit per hour
X = ratio of machine time to attention time (B/A).

Then
$$C = \left(A + B + \frac{IA}{100}\right)\left(\frac{L}{N} + M\right)$$

$$I = 50\left[\sqrt{(1+X-N)^2+2N}-(1+X-N)\right]$$

$$C = \left(\frac{L}{N}+M\right)\left(A+B + \frac{A}{2}\left[\sqrt{(1+X-N)^2+2N}-(1+X-N)\right]\right)$$

$$dC/dN = -\frac{L}{N^2}(A+B) - \frac{L}{N^2}\left(\frac{A}{2}\right)\left[\sqrt{(1+X-N)^2+2N}-(1+X-N)\right] + \left(\frac{L}{N}+M\right)\left(\frac{A}{2}\right)\left[\frac{2(1+X-N)(-1)+2}{2\sqrt{(1+X-N)^2+2N}}+1\right]$$

Setting $dC/dN = 0$ and dividing by A

$$0 = -\frac{L}{N^2}(1+X) - \frac{L}{N^2}\left(\frac{1}{2}\right)\left[\sqrt{(1+X-N)^2+2N}-(1+X-N)\right] + \frac{1}{2}\left(\frac{L}{N}+M\right)\left[\frac{N-X}{\sqrt{(1+X-N)^2+2N}}+1\right]$$

Dividing this by L and solving for M/L

$$\frac{M}{L} = \frac{2(1+X)+\sqrt{(1+X-N)^2+2N}-(1+X-N)}{N^2\left[\dfrac{N-X}{\sqrt{(1+X-N)^2+2N}}+1\right]} - \frac{1}{N}$$

II—BY WILLIAM GOVER DUVALL

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IN THE operation of automatic or semiautomatic machinery in various manufacturing processes, it becomes apparent that one operator may, in many cases, attend more than one independent machine unit with small consequent loss of production per machine per unit of time.

The cases in which this is most apparent are those in which the machine units require no operator attention while running, but which do require a constant cycle of short attention periods in order that the machine unit may be supplied with material to be processed and relieved of material processed, and that any adjustments in the course of processing may be made.

When two or more such machine units are assigned to one operator it also becomes apparent that there is a loss of output per machine per unit time. This loss is due to an idle-machine time caused by one or more of the various units requiring the operator's attention when that operator is already engaged at

another unit. This idle-machine time is defined as "interference." The operation of two or more machine units by one operator is defined as "multiple-machine operation."

It also becomes apparent as the assignment of machine units per operator is increased that the processing cost per unit output decreases to a certain assignment, beyond which it increases.

It is the function of this paper to determine the variables controlling the amount of interference in any given operation, and the mathematical relationship, or equation, expressing interference as a function of these variables. It is also the function of the paper to determine a method of finding that assignment of machine units, for any given operation, which will process the product at the minimum cost per unit of output.

In the formulas to be developed the symbols are as follows:

N = number of machine units assigned per operator
r = machine time per machine unit per unit output of product
w = operator's attention time per machine unit per unit output of product. ($w = fN + g$, see text, where f and g are constants)
I = interference as percentage of attention time
R = ratio r/w
a = cost of operating one machine unit for one unit of time (arbitrarily selected as hour for convenience); includes power, maintenance, depreciation, etc.
b = fixed overhead cost per labor hour; includes supervision, etc., and any overhead costs directly variable with labor hours rather than machine-unit hours
c = labor cost per hour; the wages to be paid the operator, either day rate or expected piece rate
d = $b + c$
S = a/d
C = cost per unit of output of product, operating N machine units per operator.
l = an arbitrarily selected number of minutes per hour allowed the operator for personal convenience.

The operating conditions under which the formulas are applicable are as follows:

(1) The operation performed on each of the N machine units under one operator's care is identical, the machine units are identical, and are equally well maintained, and the ratio r/w is therefore the same for each machine unit.

(2) The operator is equally available to all machine units.

(3) The operator is always attending one machine unit as long as there is at least one requiring attention.

(4) When any machine unit requires attention while the operator is already engaged, that unit continues to require attention (undergoes interference) until the operator is available, and is then attended by the operator for the full time required.

(5) Any time that the operator must spend at one unit, whether other units require attention or not, is attention time in so far as the values of w and r are concerned.

(6) Any machine unit undergoing either attention or interference is not liable to the probability of requiring attention until it is again running.

(7) The probability of finding the group of N units in any specified condition of interference is independent of the time at which they are noted for that condition.

(8) The various units of attention time may or may not be exactly equal; and it is assumed that the probability of a machine unit requiring attention is equal at any instant in the machine running time. This is not literally true, but over a length of operating time, the distribution of attention demands approaches the random distribution.

The general equation measuring interference is

$$I = 100\,(N - 1)e^{-1.4N^{-0.946}R} \qquad [1]$$

The development of Equation [1], may be summarized as follows: It may be observed that the amount of interference in a given machine assignment will vary inversely with the ratio of machine time to attention time. It may also be observed that when R is constant the amount of interference will vary directly with N. We may then conclude that R and N are two factors influencing or controlling the value of I.

Further consideration of the problem indicates that such factors as the variation in time required for various operator-attention periods, the distribution of these attention periods, and the operator's application of intelligence in controlling events to a certain extent may influence the amount of interference occurring on a given operation. This they undoubtedly do. However, the first two of these may be assigned a definite character in laying out the normal operating conditions to which this formula is to apply, and the last mentioned is found to be a negligible factor in actual operation. On any job which has been subjected to a thorough time and motion study, the operator's performance is well prescribed.

Now, in attempting to determine the frequency of interference occurrence through the theory of probability, we are immediately confronted with the fact that this problem is not subject to the simple analysis of the overlapping of independent events. That is, the machine units are not independent of each other in their cycle of operation, in that they must remain idle so long as the operator is engaged at other units before resuming their respective cycles. Because of this fact it is found impossible to develop I as a function of R and N in an absolutely rigorous formula.

However, inspection of the actual operating interference values, combined with further reasoning on the nature and characteristics of interference, leads to these conclusions: (1) That the final satisfactory formula may be written in the form $I = ce^{mR}$, in which c and m are constants varying with N. (2) That c may be logically derived as follows: If I and R are the dependent and independent variables of a family of curves of which the arbitrary constant is N, it is noted that as R approaches zero, or as the I-axis intercept of a curve for any selected value of N is approached, the value of r approaches zero, or the value of w approaches infinity, either of which is acceptable. When R equals zero we have a condition of no machine running time per unit of output, or an entirely manual operation. If an operator is assigned N machine units under this condition, obviously $N - 1$ of these machines must undergo constant interference, since the operator is engaged fully in producing each unit of output at one of the machine units. Then, the total interference, expressed as a percentage of attention time per unit output per machine unit, or expressed as I, equals $(N - 1)$ 100 per cent. This then is the I-axis intercept value for any value of N. (3) That m may be determined as that value which will provide a family of curves of the form $I = ce^{mR}$ which meets the value of c already developed, and which most nearly fits the actual interference values observed from machine operations.

Thus c is developed as $100\,(N - 1)$ and m is developed as $-1.4N^{-0.946}$.

In developing a method of determining the economic machine assignment the fundamental proposition is: Given a multiple machine operation, in which the machine speed is fixed and which is subject to the operating conditions already stated, to determine that number of machine units that one operator should run to process the product at minimum cost per unit of product.

The general cost equation is written

$$C = \frac{aN + d}{(60 - l)N} \left\{ r + w \left\{ 1 + (N - 1)e^{1.4N^{-0.946}R} \right\} \right\} \ldots [2]$$

It is to be noted here that w, as indicated in the symbol explanation, is not a constant, but is a variable of the first degree in terms of N.

The economic assignment may be determined at this point by equating the first derivative with respect to N of the right-hand member of the foregoing equation to zero, and solving for N, or it may be determined as follows: Assume a condition in which the values of R, a, d, and N are such that N is the economic assignment for that setup. If we let w increase continuously through an increase of g, that is, let R decrease steadily, we come to a value of R where the cost per unit output is less for an assignment of $N - 1$ machine units than it is for the assignment of N machine units. In arriving at a value of R where this is true, we must, therefore, move through a value of R where the cost per unit output of product is the same for N and $N - 1$ machine units.

It is evident that if only integer values of N are permitted, there is, for any given values of a and d, a range of R values for each value of N, in which the cost per unit output of product is lower than for any other value of N.

The values of R dividing these ranges may be determined by equating the general cost equations for N and $N - 1$ machine units. This equation is reduced to

$$S = \frac{(R + 1) + N(N - 2)e^{\frac{-1.4R}{(N-1)^{0.946}}} - (N - 1)^2 e^{\frac{-1.4R}{N^{0.946}}}}{N(N - 1)^2 e^{\frac{-1.4R}{N^{0.946}}} - N(N - 1)(N - 2)e^{\frac{-1.4R}{(N-1)^{0.946}}}} \ldots [3]$$

A chart constructed from this equation, in which S and R are the variables and N is an arbitrary constant of integer values only, reveals successive bands or zones defining the ranges of economic assignment for each value of N.

EXAMPLE

An example of application of the formulas is as follows: Given an operation subject to the specified operating conditions, in which the following data have been accurately determined from cost analysis and time study:

r = 2.000 min
f = 0.004 min
g = 0.280 min
$w = fN + g = (0.004N + 0.280)$ min
$R = r/w = 2.000/(0.004N + 0.280)$
a = \$0.15 per hour
b = \$0.05 per hour
c = \$0.40 per hour
$d = b + c$ = \$0.45 per hour
$S = a/d = 0.333$

Let l = 5 min. First we shall use Equation [2] and determine for what value of N, $f'(N)$, the first derivative of Equation 2, is equal to zero. Omitting details we have the following results: $N = f'(N)$; 4, 5, and 6 are negative; 7 and 8 are positive. Therefore, $f'(N) = 0$ when N lies between six and seven machine units per operator. Whether six or seven units produce the minimum cost may be determined by substituting for $N = 6$ and $N = 7$ directly in Equation [2].

However, with a zone chart, constructed from Equation [3], the economic assignment may be determined readily with little computation, as follows:

We have $S = 0.333$. Therefore, the economic assignment zone is determined by some abscissa R in conjunction with the ordinate $S = 0.333$.

Since R varies slightly with the value of N, we must select some arbitrary value of R which we know will be approximately correct as a trial. We select $R = 6.50$.

Now when $R = 6.50$ and $S = 0.333$ the economic assignment, or that assignment processing the product at minimum unit cost, is six machine units.

Therefore, let $N = 6$, then $R = 6.57$; and when $R = 6.57$ and $S = 0.333$ the economic assignment is six machine units, which is the final result.

III—BY HAROLD A. FREEMAN

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ON THE basis of three assumptions, as pointed out by Dr. Wright, Dr. Fry develops his fundamental equation, Wright's Equation [1], in the following manner:

Dr. Fry is interested in calculating the expected delay in service if telephone calls, all of the same length, are accommodated through a single channel. If n is the calling rate and T is the holding rate of a call, then the channel will be busy nT of the total time. (Wright writes $nT = E$.) Hence, we can find, by using the ordinary methods of probability, the likelihood that exactly 1, 2, 3, ... or j persons will want service or are being served at the same time. For instance, $P(0)$ would represent the likelihood of no one's wanting service, which would clearly be equal to the expected percentage of idle time, that is

$$P(0) = 1 - nT$$

and similarly, for $P(1)$, $P(2)$, and more generally for $P(j)$.

Since $P(2)$ is the probability that two persons will demand service at the same time, it is apparent that $2P(2)$ would give the expected length of their calls in a unit of time. Hence the aggregate expected length of all calls, which includes delays as well as uses, would be

$$\text{Total use} + \text{total delay} = 0P(0) + 1P(1) + 2P(2) + 3P(3) + \ldots = \Sigma jP(j)$$

Let $\bar{I}$ = average delay per call (equivalent to Wright's average interference per attention time) and n the calling rate. Then $n\bar{I}$ = total delay. Also, total use $= nT = E$. Thus

$$E + n\bar{I} = \Sigma jP(j) \ldots\ldots\ldots\ldots [1]$$

Dr. Fry now evaluates the summation by simple but indirect algebraic means. The result is

$$\Sigma jP(j) = (E^2 - 2E)/2(E - 1) \ldots\ldots\ldots\ldots [2]$$

Substituting [2] in [1] and recalling that $E = nT$, we have

$$\bar{I} = \frac{T}{2}\left(\frac{E}{1 - E}\right)$$

The foregoing is the basis for the analysis of Wright, who uses I, N, and X in place of Fry's I, N, and R. On the other hand, Duvall's Equation [1], as explained by the author, is entirely independent of Fry. Duvall states that he arrives at the form of [1], $I = ce^{mR}$, by considering actual interference values plus further reasoning on the nature of interference. Thus, while Duvall's approach seems primarily empirical, no serious comparison of his argument with that of Wright is possible in the absence of further information on the development of the form $I = ce^{mR}$. In correspondence, Mr. Duvall states that this development is clearly traced in his original paper, but unfortunately, this paper is not available to present readers.

THE NATURE OF THE SOCIAL SCIENCES[1]

A Review of Doctor Beard's Book

By EDWIN S. BURDELL

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NEWTON D. BAKER, former Secretary of War, told the graduating students of the Massachusetts Institute of Technology at their commencement last June, that it was their duty to "carry science into politics." This suggests that engineers and scientists have after all a double contribution to make. They must not only diligently unravel the secrets of nature in the laboratory and apply that information to the solution of problems of trade and industry, but they must participate as individuals in the everyday life of the community about them and in the larger community of the state and nation. In a word, they must be prepared to promote the successful amalgamation of technical advance and civilization to the improvement of human welfare. While such commencement-day admonitions are expected once a year, it would appear reasonable that additional comment and discussion be made on the basis of the implication in Mr. Baker's remarks concerning the engineer's knowledge of and participation in the social, economic, and political life of the world in which he lives and has his being. I use the phrase "knowledge of" advisedly, for I mean by that, knowledge and information as against prejudice, tradition, and uncritical adherence to outworn creeds and shibboleths. No colloid chemist would insist on solving his present-day problems in the paint or rubber industry solely on the theories of Graham, the founder of that field in the 1860's, nor would a present-day electrical engineer be rated very high if the best he could do was to imitate the electric motor of Siemens. Not only does machinery change, but the physical and mathematical theories on which the machinery is designed and constructed are revised and revamped without stubborn adherence to what the founders held to be true and self-evident from the standpoint of the then existing body of knowledge and experience. If the engineer is to carry science over into politics, economics, and so on, he must be prepared to be objective in matters that too long have escaped the attention of alert, agile minds rigorously trained in the physical sciences. This readiness to apply the scientific attitude and therefore the scientific method to these matters will be greatly facilitated if the theoretical fields of the social sciences be regarded with the respect and attention that they merit.

INEVITABLE THAT SOME UNWARRANTED CLAIMS SHOULD BE MADE FOR SOCIAL SCIENCES

Of course it is inevitable that some would make unwarranted claims for the social sciences and thereby bring about an equally unwarranted repudiation by those who otherwise might be induced to make a sympathetic and intelligent canvass of the material that is available. But when such cross and ill-natured criticism comes from engineering teachers as former Dean Akeley of the University of South Dakota in recent issues of the *Journal of Engineering Education*[2] then it is fitting that engineers in general should have their attention directed to such sane and cautious leaders in the social sciences as Charles A. Beard and particularly to his recent book, "The Nature of the Social Sciences."

SPIRIT OF EMPIRICISM IS POSSIBLE AND CAN BE FOUND IN THE SOCIAL SCIENCES

Dr. Beard maintains that

> . . . the spirit of empiricism—patient research and observation, abstention from hasty and dogmatic judgments, willingness to listen to conflicting evidence and opinions, judicial calm in arriving at decisions—is not only possible to the social sciences, but is as likely to be found there as in the natural sciences. A natural scientist may be strictly empirical within a given range of observation and yet narrow and dogmatic with respect to other areas about which he knows little or nothing. The social scientist true to empiricism is continually inspecting and checking his prejudices all along the line and maintains a judicial attitude toward wide ranges of subject matter. It is to social thought, rather than to findings of the natural sciences, that the world enjoys such liberty of conscience and opinion as may be vouchsafed to it today. It is the spirit of social inquiry which makes the peaceful adjustment of social conflicts possible and hence it may be called a "value" in itself, although it cannot create a real science of society.
>
> When it is said that closed schemes cannot be made out of the data of the social sciences and that there are severe limitations on the competence of the empirical method as applied to social data, this does not mean that all is chaos in the social field or that rules of operation cannot be empirically discovered in specific social areas for specific purposes. On the contrary, vast bodies of social facts are well established and systematically organized and are as "true" for human purposes as the truths of physics.

PREDICTIONS OF SEQUENCES AND REPETITIONS OF CONDUCT AND RESPONSES DEPEND ON TWO ASSUMPTIONS

He cautions us, however, that predictions of sequences and repetitions of conduct and responses are dependent on two important assumptions.

> First, such schemes of sequence are not closed and independent, they are based on the assumption that other social arrangements outside the matters brought in to the scheme will remain as they are—that, for example, the government will continue, that certain educational standards will endure, and that industrial economy will go on as before the establishment of workmen's compensation. But as a matter of fact, these social arrangements may all disappear. Second, the disclosure of such schemes of social sequence—price fluctuations, intelligence quotients, and insurance costs, does not of itself give any

[1] "The Nature of the Social Sciences in Relation to Objectives of Instruction," by Charles A. Beard. Charles Scribner's Sons, New York, 1934.

One of a series of reviews of current economic literature affecting engineering prepared by members of the Department of Economics and Social Science, Massachusetts Institute of Technology, at the request of the Management Division of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

[2] May, 1935, pp. 633–638; May, 1936, pp. 726–728. In fairness to the educational policy of the journal just cited, it must be stated that they have also carried a very favorable comment by Williard E. Hotchkiss, president, Armour Institute of Technology, on the importance of the social sciences in Engineering schools. *Journal of Engineering Education*, September, 1935, pp. 86–95.

indication respecting any policies or actions to be based upon such findings. All the economist, psychologist, or sociologist can say is: "This is what happens in the given circumstances; and, *if* you decide to do this or that, this is what will probably happen, assuming the continuance of the circumstances." Obviously such a statement is entirely different from the proposition that a body suspended in air is heavy with respect to the earth in the proportion of its mass and distance—always and everywhere.

A PARTIAL EXPLANATION OF DIFFERENCE IN NATURAL AND SOCIAL SCIENCES OFFERED

A partial explanation of the fundamental differences between the natural sciences and the social sciences lies in the difference both in bulk and complexity of knowledge and thought in that broad dichotomy. For instance, contemporary knowledge and thought about chemistry is to be found in relatively few places but there are millions of books and papers pertaining to human affairs, to say nothing of the individual opinions of hundreds of leaders in business, politics, and religion. It is conceivable that all the information relating to any one field of pure or applied science could be assembled in one place, but such an idea of doing the same for the social sciences would be absurd. Another fundamental difference that needs to be emphasized because it is the cause of so much false assurance of neutrality and objectivity is the position

. . . that the observer and thinker in the social sciences stands in a relation to actuality, record, and knowledge which is different from that of the observer and thinker in such real sciences as chemistry and astro-physics. The thinker who deals with chemicals and stars stands outside the objects observed, at least in the common-sense view. In the case of the social sciences, the thinker floats in the streams of facts, so-called, which he observes. His thoughts are parts of the thing thought about. The student of social affairs is not an abstract human being, timeless and placeless. He thinks as an American, an Englishman, a German, or a Japanese, for instance, and at a given time in history. And within his own country he is a resident in some geographical area, a member of a class, group, or profession, each with its more or less different type or style of thinking about social matters so vital to its security, prosperity, and welfare.

DIFFICULTY OF ISOLATING DIVISIONS OF SOCIAL SCIENCES AND OF EXPRESSING ACTUALITIES IN MATHEMATICAL TERMS

Dr. Beard takes up in order history, political science, economics, and sociology, but not as clean-cut divisions of the general field.

. . . the student may concentrate his attention on economics, politics, religion, art, amusements, or history, but he cannot isolate his materials after the fashion of the chemist. In real life all these phases are so interwoven and interlocked that it is seldom possible to discover where one begins and the other ends. The same thing—man—is doing various things from various motives and amid frequent changes and in different ways, while chemicals always perform the specific functions which it is in their nature to perform under given conditions. Owing to this interlocking relationship of the diverse aspects of human nature, none of the social studies, such as economics and politics, has been able to work out a body of formulas as indubitable and unchallenged as those of the arbitrarily limited sciences, such as chemistry or hydraulics. Moreover owing to the development of human experience, men and women as individuals, and as groups, races, and nations, are always growing and changing, so that in the realm of complex human relationships, patterns of individual and social ideas and interests are not repeated in time with that exactness found in the sequences of physical nature. Hence any division or cross-sectioning of human affairs is arbitrary and artificial and can only be justified by convenience and by recognition of the impossibility of grasping the whole scheme entire.

Not only is it impossible to isolate divisions of the social sciences, as the chemist does his materials; it is impossible to express all the actualities, with which any one of the social scientists deals, in the mathematical terms which are absolutely indispensable to operation in each field of natural science. If anything is known at all, it is that all the facts or data of the social sciences or of any one of them cannot be brought within a scheme or closed circle of deterministic sequences or completely specified by finite numbers.

THERE IS AND CAN BE NO SCIENCE OF SOCIETY IN THE GENUINE SENSE OF THE TERM

The conclusions reached by Dr. Beard are surely disarming to such charges of superarrogation of omniscience and infallibility so freely ascribed to the social scientist by such critics as Dean Akeley.

Either the data of the social sciences treated individually and collectively are by their inherent nature susceptible of formulation in mathematical terms and in deterministic sequences in such a manner that it is possible to predict what will happen when any portion of the social sequence composing the whole scheme is observed, or the data of the social sciences cannot be so treated. Can the data of the social sciences be so treated? If any real science, from which the empirical method is borrowed, cannot explain but can merely describe, can the social sciences accomplish by the scientific method what is impossible to the real sciences? These questions seem to answer themselves. There is and can be no science of society or partial science of society, such as politics or economics, in any genuine sense of the term.

In fine, then, we may regard as closed the question whether there is any such branch of knowledge as social science in any valid sense of the term as employed in real science. There is none. There is no reason for assuming that any deterministic science of human affairs or any part of them is possible. It follows also, that there are no exact subsidiary social sciences, such as economics, politics, or sociology, despite much display of learning under these heads. Each of them deals with the same indeterminate, man, and besides rests upon assumptions respecting related fields over which neither it nor its subject matter can exercise effective control. That is, a science of the State assumes the existence and continuance of economy and yet it cannot assure the perdurance of the economy upon which it depends for its life blood. The science of economics, in turn, assumes the existence of order on a large scale and yet economy cannot assure the order necessary to its efficient functioning. Such conclusions may be distressing to those hungry for "the final word"—for a neat, closed system of thought to be imposed upon the plastic mind of youth as an "explanation" of everything and sure to produce harmony and prosperity if "applied;" but they are the conclusions to which we are led by a patient examination of the literature and nature of the so-called social sciences.

SCIENTIFIC METHOD IS A PRECIOUS AND NECESSARY INSTRUMENT IN SOCIAL SCIENCE

However, lest these frank statements would seem to unduly discredit and perhaps destroy confidence in the validity of this field of learning, Dr. Beard does insist that

. . . the social sciences embrace large bodies of organized and authentic knowledge respecting human affairs—knowledge, which is absolutely indispensable to the conduct of individual life, the management of economies, the government of nations, and the adjustment of international relations. Deprived of these bodies of knowledge, modern civilization would sink down into primitive barbarism. The more complex contemporary life becomes the more indispensable are the social sciences to the continuance and advancement of civilization.

The empirical or scientific method employed in the social sciences is a precious and necessary instrument for the accumulation and authentication of knowledge and for drawing conclusions, especially in areas of social data peculiarly susceptible to mathematical treatment. Competent conduct and administration in private affairs, industry, agriculture, and government—local, state, and national—are based upon findings of fact and upon rules or axioms drawn from the study and observation of social actualities and records. This remains true, although there has been created no real science of society or of any division of society, political or economic.

ENGINEERING PROGRESS

A Review of Attainment in Mechanical Engineering and Related Fields

BECAUSE the editor of this section, who has abstracted the articles that have appeared in it since the establishment, in 1912, of the "Foreign Review" as it was then called, is on leave of absence, space devoted to the abstracts has been reduced.—EDITOR.

AIR MACHINERY

Rotary Compressed-Air Motor

THIS motor has been developed in Germany and employs only a single rotor, shown in the center of Fig. 1. The smaller circles on each side represent sealing rollers and transmit no torque.

It will be seen that the rotor is made with a number of radiating fins and teeth, and runs in a cylinder. If air is admitted to the space between adjacent teeth and the cylinder walls and is allowed to exert pressure on one face of one tooth only, it is clear that a turning moment will be set up. The function of the side-sealing rollers is to partition off the annular spaces between the teeth in such a way that only one tooth face in those spaces is exposed to the air pressure.

The air supply is indicated in the illustration at *a* and enters the spaces through ports in the casing at opposite quadrants of the rotor. In the top left-hand quadrant the inlet port is fully opened and the air pressure is acting wholly upon one tooth, turning the rotor in a clockwise direction. In the bottom right-hand quadrant the turning moment is similar in quantity and direction, but for the space of time taken by the following tooth to leave the right-hand sealing roller, the effect of the pressure will be partly balanced by the uncovered portion of that tooth. As the number of teeth is uneven, however, it is impossible for the rotor to get on a "dead center" during the passage of the tooth across the port. The exhaust ports are shown at *b* and need no comment. Reversing is effected by the control valve, which is of the rotary type and merely changes the pressure-air supply to the opposite sides of the casing.

The sealing rollers and the rotor rotate in opposite directions and the speed of the former is such that the grooves in them synchronize with the teeth of the rotor. The sealing rollers are driven by hardened and ground steel pinions from a spur wheel of similar material on the rotor shaft, and are grooved circumferentially to take the flanges forming the seal at the ends of the rotor teeth.

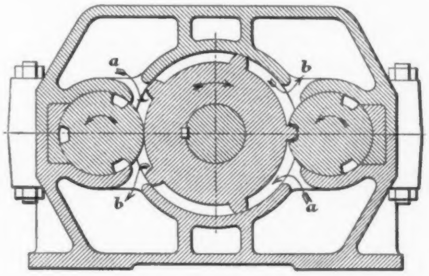


FIG. 1 SINGLE-ROTOR COMPRESSED-AIR MOTOR

So far, a rotor having one ring of teeth extending for its full length has been dealt with, and exhaust takes place at high pressure, but in the larger sizes expansive working is employed. In these, the rotor is divided lengthwise into two or more sections by circumferential rings, the teeth in adjacent sections being staggered. The air exhausted from one tooth space is then passed to the driving side of a tooth space in the adjoining section. The casing is made dustproof for use in mines, and is divided along the horizontal center line for inspection and overhaul of the rotor. The air supply is controlled by a centrifugal governor and a filter is fitted. (*Engineering*, vol. 141, no. 3669, May 8, 1936, p. 520, 1 fig.)

APPLIED MECHANICS

Some Features of the Behavior in Bending of Thin-Walled Tubes and Channels

STRESSED - skin components and structural elements of the tubular or light-channel type are becoming increasingly popular in aircraft structures. As in certain respects the commonly accepted theory of bending is not applicable in these cases, it was considered desirable to examine the bending characteristics of such structures with particular reference to shear stresses and the position of the flexural axis. This report, therefore, deals primarily with the two closely related problems of finding (*a*) the bending-shear stresses induced when a beam of thin-walled section is laterally loaded at its flexural axis, and (*b*) the flexural axis for thin-walled sections.

For the case of thin-walled sections, simple and readily applicable solutions are possible. It is shown that the shear stresses in the flanges of either closed tubular sections or open channel sections, where the flange of the section is wide and its thickness is comparable with, or less than, the thickness of the web, may be important. It is also demonstrated that for the average open section the flexural axis is completely outside the section. (D. Williams, British Bureau of Scientific Research, Air Ministry, Reports and Memoranda, No. 1669, Feb. 28, 1935, 13 pp. and 15 diagrams)

ENGINEERING MATERIALS

Two Lightweight Concrete Aggregates

ONE of these has been produced from slate waste. It is known that appropriate heat-treatment of certain clays and shales causes them to expand to give a product suitable for use as an aggregate for lightweight concrete. When certain kinds of slates are heated to a sufficient temperature they lose the characteristics of slate such as cleavage, and expand to many times the original thickness to give a product containing a large number of cavities which make the material light enough to float on water.

For expansion to be possible it is evident that the slate must be of such a composition that it commences to fuse just before the evolution of the gases. The rate of heating must be rapid or the gases will be generated so slowly that they will be dissipated without expanding the slate. All slates do not expand to the same extent.

In order to obtain a light aggregate from slate waste the material is crushed and heated in a kiln suitable for continuous treatment of granular mate-

rials, such as rotary kilns, used in cement manufacture.

Expanded slate contains only small amounts of salts soluble in water and is not attacked by soluble salts formed by atmospheric gases derived from cement. An analysis of the soluble material is given in the original article. The expanded-slate concretes have satisfactory properties for nailing and sawing.

The plastering qualities of partition slabs made with expanded slate, as with most other lightweight aggregates, are good. Cement, lime, and gypsum plasters work well on the slabs, and it has been found that the suction of the slabs is not so great as to require preliminary wetting down. The slabs afford excellent key for the plaster, and when tested for adhesion the plaster has been found to break before the bond failed.

Investigations have also been made of the possibility of using lightweight concrete mixes in reinforced-concrete structures. Preliminary tests have shown that by replacing the finer portion of the lightweight material by sand it is possible to achieve adequate strength. The density of the concrete is, however, increased. (E. H. Coleman in *Concrete and Constructional Engineering*, January, 1936, pp. 47–51, 1 fig., and 2 tables)

The second of the lightweight aggregates is the so-called "foamed slag." Foamed slag is a cellular lightweight aggregate produced by rapidly cooling molten blast-furnace slag of suitable chemical composition by a patented process. The molten slag is transformed into a material having an amorphous, glassy, and highly cellular structure, which remains inert and will not decompose. In this way it differs from slag in the air-cooled state as known today, which has a recrystalline structure and in some cases is subject to disintegration.

A feature of the new aggregate is that it has hydraulic qualities of its own. Its chemical analysis is substantially identical with that of Portland cement in so far as its constituents are concerned, the difference being in their proportions.

Foamed slag is produced only from blast-furnace slags used for the manufacture of blast-furnace-iron Portland cement. Steel slags are not suitable. As it is produced at a temperature of about 1400 C foamed slag cannot contain free sulphur. It is also said to be free from loam, clay, and other organic matter.

The porosity of foamed slag differs substantially from that of pumice, its pores or cells being sealed, or self-contained, whereas the pores of pumice have a capillary structure which is responsible for the high water content and very slow-drying qualities of pumice and pumice concrete as compared with the new material which is produced at a very high temperature and can therefore be retained perfectly dry. By reason of its cellular nature, foamed-slag concrete will dry out in a very short time.

The weight and crushing strength of foamed-slag concrete can be adjusted within wide limits according to requirements and depend on the combination of various grades of the aggregate, the proportion of the cement, and the method of tamping.

Additional strength and density can be obtained by adding sand to the concrete mix and there is a great increase in crushing strength from 28 to 90 days. (*Concrete and Constructional Engineering*, vol. 31, no. 2, February, 1936, pp. 148–150, 2 figs.)

MACHINE PARTS

Automobile Pistons Cast From Alloy Steel

THESE pistons are poured in "all" green-sand molds, that is, the core is green sand, as well as the mold, the pistons' being poured in a horizontal position is said to be violating all theory, tradition, and custom connected with castings of this character. The department devoted to the production of the pistons is partitioned from the remainder of the building and air-conditioned.

The nicest control is necessary to hold the sand in ideal condition, moisture, permeability, and green-sand strength. If the sand is too hard, too thin, and tender, the casting will crack. If the sand is too soft the casting will be oversize and overweight and will be rejected. A slight excess in the degree of moisture or density will cause the metal to flutter with resulting pin holes in the machined grooves for the oil rings.

The rough casting weighs 650 grams, while the finished weight is held between 301 and 305 grams. The thickness of the finished wall is held between 0.030 and 0.035 in. The outside diameter of the rough casting must not exceed the anticipated measurement by more than 0.010 in.

Green sand for securing such a fine degree of accuracy is rammed harder than usual in green-sand practice. Physical characteristics of the particular sand employed show permeability 65, bond 9 to 10, and moisture between 2.8 and 3 per cent, according to American Foundrymen's Association standards. In closing one part of the mold the drag with suspended cores is lowered into the cope. Later the entire mold is turned up on end for pouring. The green-sand cores without any apparent support retain their position whether hanging vertically from the face of the drag or extending horizontally from the same face. (*Steel*, vol. 98, no. 24, June 15, 1936, pp. 48–53 and 67)

POWER-PLANT ENGINEERING

Valves for High-Pressure Power-Plant Piping

HIGH-PRESSURE-steam gate valves and fittings here described were designed for maximum condition of 1350 lb gage steam pressure and 850 F total temperature. The maximum condition in feedwater lines is 1800 lb gage pressure and 450 F temperature. All gate valves are designed to open and close under a full flow of steam or water. Bonnet equalizing lines connected into the regular by-pass pipes are provided to balance the pressures on the top and bottom of the gates when they are being moved off their seats. The bodies and bonnets of these valves are chrome-molybdenum steel castings, with gates of the wedge type of chrome-molybdenum steel having stellited faces. Valve trimmings are of stainless steel or iron. Special valves of the globe pattern for high pressures and temperatures for the desuperheating of steam, automatic intercepting valves in steam lines between turbine and reheater, feedwater-control valves, stop and check valves, and others, have materials of construction similar in their parts to those of the gate valves. (H. H. MacMillen in *Power Plant Engineering*, vol. 40, no. 5, May, 1936, pp. 307–308)

STEAM ENGINEERING

"Kinetic Motor"

IT IS stated that a four-cylinder engine has been constructed and two more of much larger size are now under construction. The four-cylinder machine has three pistons, each having an area of 1.25 sq in. The pistons are secured to a rotor gear at 120-deg intervals. Each piston receives a power stroke in each cylinder in one revolution, the resultant work of the three pistons being twelve impulses per revolution.

The first machine built developed 3.65 bhp at 1000 rpm and 90 lb pressure. It was operated by air and showed a consumption of 19 cu ft of free air per hp per min. The new engines are to run on steam. (*Modern Power and Engineering*, vol. 30, no. 4, April, 1936, pp. 25–26, 3 figs.)

LETTERS AND COMMENT

Brief Articles of Current Interest, Discussion of Papers, A.S.M.E. Activities

Specifying Lubricants

To the Editor:

Mr. Lehman, in November, 1935, Mechanical Engineering, page 732, approves the conclusions reached by Virgil M. Palmer and Horace F. Smith in their paper "A Lubrication Program."[1] He states that it would lighten the task of engineers specifying lubricants if the names of the thousand or so lubricants, mostly meaningless in themselves, could be reduced to 25 to cover the whole field of lubrication, each name giving the use of the oil in general. The lubricant specified could then be obtained throughout the country.

Mr. Harris, January, 1936, Mechanical Engineering, page 60, states that most mechanical engineers are faced with lubrication problems, and are supplied with a heterogeneous mass of sales and misinformation about lubricating oils, when the problem of lubrication is today greatly intensified with the high-speed and heavy equipment. He then suggests that one way to improve the situation would be for the Society to sponsor the development of a standard specification, carrying this work out in cooperation with all other engineering societies.

Some such practical course of action has seemed necessary for some time in order to satisfy machinery designers, the users of lubricating oils and greases, and the manufacturers and sellers of lubricant products. The Lubrication Engineering Committee of the A.S.M.E. Petroleum Division had the matter under discussion for several years prior to 1933. A decided but slow trend was noticed regarding a reduction in the marketing lists of the major oil companies. The S.A.E. numbers had been successfully promoted by the oil industry and the S.A.E. to the public; the Navy had finally reduced its entire requirements to 17 different oils, and the oil companies had welcomed these reductions in working brands, as the system saved much duplication and confusion in handling, storing, and marketing, and made it easier for the salesman and greatly pleased the customers. This trend seemed to indicate that this simplified system could be extended to industry in general with much benefit. Requests have come to the A.S.M.E. from machine designers for help in clearing away the confusion that exists as a result of the long lists of unrelated oils now being offered by the oil industry.

Further, the A.S.M.E. has received a number of reports from the users of industrial equipment stating that the situation has become so complicated that they had tried to correct a part of it by using, on their industrial equipment, the S.A.E. ratings for oils. However, they report, this did not meet the industrial requirements completely because the S.A.E. classifications are too broad to cover the many types of industrial service with general satisfaction. Other forms of specification have also been considered by these groups, i.e., those used by the General Motors Corp., but it was considered that these specifications were too complicated for general application.

The A.S.M.E. Lubrication Engineering Committee then took the matter up with the sales-department executives of various oil companies and discussed with them the many economical points involved. It was reported that some of the large oil companies thought that something of the kind proposed would greatly cut down the expenses of manufacturing, storage, transportation, and marketing on the part of the handlers of lubricants. At the same time there would be provided a reasonably simple and safe system of numbering oils so the machine designers would be furnished with a standard guide for their work, from which they could safely specify the kind of oils to be used on the finished machine, a highly desired procedure which is not possible at present.

After these opinions were received it was agreed that A. E. Becker would prepare the leading paper on the subject at the Seventh Oil Power Conference devoted to lubrication engineering, held at the Pennsylvania State College, May 25–26, 1933, and C. M. Larson would supplement it by a second paper or discussion. These papers are to be found in P. S. Technical Bulletin No. 18 beginning on page 76 with Dr. Becker's paper "Viscosity Classification for Industrial Lubricants," followed by Mr. Larson's discussion, and discussions by H. A. S. Howarth, Leonard Raymond, Mayo D. Hersey, C. H. Fellows, J. G. O'Neill, and E. R. Woodward, all of whom approved the proposition from the users' point of view. Only one disapproved the proposition.

The meeting then passed a resolution (see page 95) suggesting that the A.S.M.E. request the A.S.A. to form a committee to develop a simple, significant, and readily interpreted viscosity classification system for industrial lubricants.

Pursuant to this resolution, the A.S.M.E. addressed a letter to the A.S.A. transmitting this suggestion which in turn called a conference for a general discussion of the proposal. This conference was held on April 18, 1934, there being present representatives of 14 national societies. On the morning of the conference, it was found that two of the A.S.M.E. representatives (engineers employed by oil companies) had been ordered either not to attend the meeting or to oppose the proposal, although these companies had previously indicated approval of a simplified program in regard to the marketing lists. The A.S.M.E., sponsors of this proposal, therefore, had a greatly reduced technical representation at the conference.

At the meeting, two points of view were expressed; first that lubricants could be usefully classified by viscosity numbers, and second that viscosity was only one of the several important factors, all of which would have to be considered in classifying lubricating oils. This, however, is not done with the supposedly much higher technical markets served by the S.A.E. motor oils that are classified by viscosities only. A vote was taken on the resolution that it was desirable to undertake the classification of industrial lubricating oils by viscosity numbers under the auspices of A.S.A. This resolution was lost by nine votes to three, one of the representatives not voting.

[1] Mechanical Engineering, vol. 57, September, 1935, pp. 565–570.

The work of setting up the proposed classification was later turned over to A.S.T.M. to sponsor alone, and the matter is now with a committee covering all petroleum products. In the discussions of this last move it was pointed out that the A.S.T.M. was well organized, and doing good work in standardizing testing methods for materials. From the nature of this work, it was pointed out, A.S.T.M. was a producer's organization, operating through the producer's chemist. On the other hand the A.S.M.E., in proposing a program for the study of some simplified form of numbering the lubricants, was acting principally in the interest of the engineer, machine designer, and the engineer representing the ultimate consumer of such oils.

If the opinions of Messrs. Palmer, Smith, Lehman, and Harris do represent those also held by other engineers who have to do with machine design and lubrication, let them continue to express themselves. This will make it possible for the A.S.M.E. to urge effectively the consideration of the viewpoint of application of the lubricant to the existing machines in general industry as well as to the design of new machines for the proper use of such standardized lubricating oils.

William F. Parish.[2]

[2] Chairman, Lubrication Engineering Committee, Machine Shop Practice Division of the A.S.M.E., New York, N. Y. Mem. A.S.M.E.

Labor and Electrification Problems

To the Editor:

In the April number of your journal I noticed an article by John P. Ferris, who, the footnote tells us, is officially connected with the Tennessee Valley Authority. Notwithstanding the author's statements that his views are personal, they do constitute effective New Deal propaganda. The drift of the paper is, apparently, that to make income balance outlay the rural areas must be industrialized, and therefore must be given a supply of electricity for local power uses.

Since you are drifting so far from the proper sphere of mechanical engineering as to include in your magazine economic and even semipolitical articles—which I do not say is undesirable—is it too much to ask that you allot a little space to an old member of the Society who, after 20 years as a professional engineer, has chosen to spend the remainder of his life in one of the rural areas your paper refers to and has for 25 years operated an agricultural enterprise therein; and who may, therefore, be supposed to know something at firsthand of the matter Mr. Ferris discusses?

The National Administration has since 1933 held to the view that there was too much agricultural production, and therefore that agricultural products must be restricted by force if necessary. It was also a matter of undisputed knowledge (sic) that there were too many manufactured articles produced. Therefore, neither class could sell its products, although each wanted what the other had. The industrial class reduced its output by enforced idleness, and could do this because of its industrial organization. The Administration then tried to enforce the same policy on the rural class. Neither class benefited by the enforced restriction.

The monkey wrench which stopped the machinery has been quite obvious from the beginning, but nobody has cared or dared to mention it. When ordinary laborers and artisans in the cities are receiving a wage of $5 to $10 a day (for eight hours) and rural workers have received 50 cents to one dollar a day of ten hours *or more*, can there be any question as to the causes of the impasse in the exchange of goods between city and country?

Naturally the cost of goods produced by the $5 and $10 men is such that they cannot be bought by the 50 cent and $1 men. What ought to be pointed out and emphasized is that industrial wages in this country have been forced continually upward since the eighties of the last century, always with public approval and the help of the administration to bring about combinations of labor unions until at the present time the entire aggregation of trade workers are united in a single organization which dictates wages of laborers throughout the country.

The depression worked no such reduction in union wages as it did in those of farm workers (and the latter includes farm owners who get far less, per hour, for their own labor, than the nominal scale of 50 cents to a dollar a day). Quite the contrary. If they could not raise the rate per day, they at least raised the rate per hour by cutting their time from eight to six hours per day or even less. This had the same effect, obviously, as adding 25 per cent or more to their real wages. It did not help the situation, of course, because at the higher rate of wages there was even less sale for manufactured goods.

It is my firm conviction that, had the wages of industrial workers been free from monopoly and government manipulation, had, in short, been fixed like other commodities by the ratio of supply and demand, several important results would have followed: First, there would have been no such intense concentration of industries in metropolitan areas; second, both rents and prices of manufactured goods would have been lower; third, wages would have been enormously lower, thus enabling rural producers to buy manufactured goods and in turn lower their prices, and still provide enough for a comfortable, quiet living for city workers, both artisans and "white collar" workers; fourth, there would have been no industrial depression lasting for years.

That the present economic conditions wherein "labor" is substantially a monopoly aided by the government are artificial and cannot endure if our civilization does, is as certain as sunrise; even though at this moment, we cannot see our way to the end. That the resulting living conditions among this large fraction of the population have become morbid to an extreme degree cannot be doubted by any one who has 60 or more years behind him and a perspective which extends back for several centuries.

It would seem that manufacturing costs have risen so high because of extortionate wages that it will result in a disintegration or decentralization of industry and a shattering of the labor monopoly in the end. Until then, no forced drug injections by the government can restore the position of the rural workers in the economic scheme.

The Tennessee Valley scheme to introduce electricity generally on the farms is just another of those schemes that have been so characteristic of the present Administration. I can assure your readers positively that the amount of good it will do in raising the standard of living among the farmers will hardly be visible in a magnifying glass. I can say with entire positiveness that there is not one in ten, possibly not one in fifty, of the farmers of this country who would subscribe to the service if offered at the lowest price on record; if the power lines ran by their door. And they would be right, because electricity would be an expensive and almost useless luxury to them. Electricity is not what they want or would care to pay for when they need and cannot buy so many other things vastly more important. Lastly, while

this institution, which I manage, *does* need electricity. I can aver with equal positiveness that it would not subscribe to any power-line service, whether for light or power, as I prefer to run my own independent system. It is such a pity that so much money is being uselessly frittered away on idle and visionary schemes begotten in the minds of "brain-trusters" who probably, most of them, would not know a plow from a harrow if they saw one.

GEORGE W. COLLES.[3]

Misuse of Term Engineer

TO THE EDITOR:

The term "engineer" and the profession of engineering have clearly been defined in the "model law" and in laws enacted in many states.

As we do not call a bricklayer a structural engineer, a carpenter an architect, a rodman a civil engineer, a machinist a mechanical engineer, a prescription clerk a chemical engineer, a farm hand an agricultural engineer, nor an electrician an electrical engineer, why call an engine operator an engineer? Why not use some name that would honestly describe him and his highly respectable and important trade?

It is true that the usage of the term "engineer" in connection with engine operation dates back to the time when engineers built steam power plants and applied the ancient term "engine" to the new mechanism. Misusage of the term started as these engines were improved so that any one could be trained to run them. When the real engineers turned their efforts to advancing design and construction and operators were hired to tend, shovel fuel, start and stop, and oil, these operators were nicknamed "engineers." A misusage so comparatively recent will never materially affect the correct and ancient usage, which will survive; and the suggestion that the real engineers relinquish their professional and legalized title to a smaller and dwindling group that has no real claim to the term or what it stands for is untenable. The engineer must be on his guard and individually and through his professional societies actively to defend his title against all unqualified users.

Newspapers must be asked to help educate their reportorial staffs as to what the designation "engineer" means. Directories, rosters, government documents, and telephone books should be examined, and pleasant, if possible, but firm and inflexible efforts must be made to stop its use in every unauthorized manner.

Unions, brotherhoods, and other associations of enginemen and their members should be persuaded to discontinue incorrect usage of the term. If the term "engineer" appears in their association name or trade magazine, they should be asked to change it.

All that is necessary is to change the last syllable of one word "engin*eer*" to engin*ist* or engine*man*, or engin*ician*, if an entirely new word is felt undesirable.

Can there be anything unreasonable about this?

Possibly the title "practical engineer" could be conferred upon present users of the title whose only claim to it is years of usage and who hate to give it up, while future recruits to the ranks of engine operators could be restricted to the new and proper term.

The present confusion is a nuisance not only to the public but to the two groups themselves and is the cause of frequent misunderstandings, but the campaign for better general information on the correct usage of the term "engineer" will largely eliminate these and work toward narrowing the usage of the term to its proper sphere.

HARRY E. HARRIS.[4]

Production and Distribution

TO THE EDITOR:

So much has been said to the effect that the problem of production has been practically solved and that the remaining problems are largely those of distribution, I wonder how many will be shocked if I express my belief that the problem of production has not yet begun to be solved and that if it were, distribution would take care of itself. Furthermore, there is no such thing as a separate problem of production and one of distribution. Both are parts of the general problem of circulation. This is, in fact, the same problem which is faced by the designer of a steam plant, a water, gas, or electric-supply system, and also by a physician in considering the ills of the human body.

Investigation shows that production processes become ever more complex, costly, and inflexible even though the cost of separate operations is cut. It now takes twice as much capital to produce a given product value as was needed in 1850. The difference is only partly in the growth of overhead as such.

Percentage overhead has necessarily increased and labor has decreased in terms of product value, but both these costs have decreased and raw-material costs have also decreased in terms of invested capital. Capitalism is thus only half as efficient, in an economic sense, as it was, although we pride ourselves on its increase of efficiency in a technological sense. Add to this production inefficiency the increased waste of distribution and it is easy to see why the economic body has indigestion and needs a dose of salts rather than more food. Public works increase the indigestion and should be abandoned entirely as far as government action goes. Instead we should have a vast conservation campaign, on a far larger scale than anything hitherto conceived.

Added to the conservation campaign, which should include the conservation of human resources, there should be:

(1) A rage for simplifying production—fewer styles and parts, and simple devices instead of costly machines.

(2) A salvage system in which government, town, state, and federal, would demolish old buildings to make room for new, buy ones built with private capital and used articles of every kind on a national scale.

(3) Make labor more mobile by elementary technical education and by economic education of those groups, labor unions, and others, who violate common sense by creating a fixed caste system.

(4) Budget labor costs as a fixed percentage of product value, as is actually done now by some progressive concerns. Spend ingenuity in cutting percentage of nonlabor costs. This does not mean high money wages at all times but a fixed percentage for wages.

If the foregoing plan were followed and some of the complacency removed from the minds of the engineers, who have done a brilliant job scientifically but a poor job economically, we would have sufficient purchasing power to create demand for all production which suits the public taste, and distribution would be almost automatic except as interfered with by inflation, speculation, and monopoly. These latter points are appropriate subjects for governmental action.

WM. F. TURNBULL.[5]

[3] Rose of Sharon Garden-Ranch, Rosharon, Texas. Mem. A.S.M.E.

[4] Consulting Engineer, Bridgeport, Conn. Mem. A.S.M.E.

[5] Tuckahoe, N. Y. Mem. A.S.M.E.

REVIEWS OF BOOKS

And Notes on Books Received in the Engineering Societies Library

American Agriculture

American Agricultural Conditions and Remedies, National Industrial Conference Board Studies, No. 224. National Industrial Conference Board, Inc., New York, N. Y., 1936. Paper, 6 × 9 in., 57 pp., $2.

Among the numerous reasons why engineers should be informed on American agricultural conditions and remedies, three may be emphasized: The agricultural problem has been a major national issue for years, is particularly acute in the present political campaign, and will continue to engage our attention for years to come. It involves the economic health of the nation no less than social and political stability. Second, engineering has contributed changes to modes of life that have not only raised the standard of living of the farmer but have provided him with a potential desire for a host of industrial products and engineering services. And finally, engineers, mechanical engineers in particular, are engaged in activities that look in a large measure to farmers for a market.

In the National Industrial Conference Board's pamphlet under review an attempt is made to deal rationally with American agricultural conditions and remedies. Readers will find it a source of information and understanding that should greatly assist in formulating a balanced view of a perplexing problem.

Commencing with conditions in American agriculture as they exist today, as shown by a field survey, the pamphlet describes three types of farming:

(1) Highly commercialized farming, where the primary objective is cash income and the method used is specialty production for the cash market. Kansas and Montana wheat farms, California hog ranches, Florida sugar and Louisiana cotton plantations are extreme examples.

(2) Subsistence farming, where the primary objective is existence and the method is too often the avoidance of any unnecessary effort. Examples are to be found where climatic conditions are not severe and where submarginal farms are being worked by submarginal farmers.

(3) The family farm, where the primary objective is the development of a long-time family home and worth-while life. The method used is diversified farming, the production of a major portion of the food and feed needed for farm consumption and of extra or specialty crops for cash income.

The desirability of emphasis in favor of the "family farm" is clearly discussed and it is pointed out that "there is no lack of land available for the small family-farm type of agriculture and present prices are, to say the least, reasonable." Moreover, agricultural colleges are turning out young men and women fitted to manage such farms. Of the two strong incentives to overproduction, debt and taxes, debt can best be insured against by the carefully managed family farm, and taxes by reduction in the cost of government.

In discussing farm prices and income, a table of income per farm operator in cash and kind for farm production alone is presented, which shows totals for the United States of $1335, $590, and $795 for the years 1929, 1932, and 1934, respectively. Government rental and benefit payments are excluded.

A chapter is devoted to past attempts to help agriculture. For at least 50 years the states have been receiving federal funds for agricultural education and research, and many services have been established. Most have helped the public in general and the progressive farmer.

The pamphlet points out that in recent years the farmer has received much tariff protection, and that many of the goods he purchases have been on the "free" list. Reciprocal trade agreements, while helping farmers in certain cases, are likely to be of greater benefit to industry in increasing its exports.

Agricultural cooperation, such as cooperatives for buying and selling, come in for commendation where they have cheapened the marketing process, increased demand, and fitted quality and regularity of production to demand.

The failure of the Federal Farm Board and the effects of revaluation of the currency are noted. Considerable space is devoted to an exposition and analysis of the Agricultural Adjustment Administration, with the conclusion that "gross farm returns cannot be increased with such a program," although net returns may be temporarily increased by reducing labor forces. The soil-conservation program to which the Administration turned after the invalidation of the A.A.A., brings forth the comment that "soil conservation as such is constructive, but it affords no sound basis for crop reduction."

Attempts at agricultural control in other countries—rubber and wheat, for example—are briefly mentioned with the warning that "even for military reasons those controls are dangerous. . . . The most unfortunate feature of schemes which promise an easy solution for the difficulties of agriculture is the regimentation which is involved for the farmers. . . . Experience with regimented control in cotton and tobacco in the South shows that it tends toward a freezing of economic progress and prevention even of the necessary economic change to meet current developments."

In presenting a positive program for agricultural improvement the pamphlet reproduces two charts, one showing that cash income from the sale of farm products in general rises and falls with agricultural production, and the other showing an almost perfect correlation between the cash income from farm products and the income of industrial workers, a striking proof of the interdependence of agriculture and industry.

The program prepared involves first, the expansion of the actual net cash farm income by restoring domestic markets through industrial recovery and a stronger foreign-trade policy, and by increasing the demand for farm products through business recovery and stimulation of changes in the national diet. Second, farms should be made more self-providing, especially in regions largely given over to commercialized farming, by growing for themselves more of what they consume in food and feed and by removing such obstacles as the present tenancy and mortgage system. Furthermore, the pamphlet points out, it would be good policy to withdraw certain wheat lands in the subhumid regions of the great plains, and add them to the public domain or use them for the production of beef cattle and sheep.

Finally, it is shown that "much of the present rural population needs outside

income to augment what it gets from the farm. Industry can help to supply this income." "Problems of distribution of farm products could be greatly simplified and real income increased by the establishment, where practicable, of small industries in farming communities."—G. A. S.

Rockets Through Space

Rockets Through Space—The Dawn of Interplanetary Travel. By P. E. Cleator. Simon and Schuster, New York, 1936. Cloth, $5^1/_2 \times 8^1/_4$ in., 227 pp., illus., $2.50.

Reviewed bx Alexander Klemin[1]

THE situation with regard to rocket flight in some respects is similar to that which existed a few years before the epoch-making flights of the Wright brothers. There are many rocket societies in existence in the United States, England, Germany, and other countries. Hundreds of amateurs or technicians considering their efforts as a hobby are at work on various phases of the rocket. Neither scientists nor engineers are as yet willing to admit fully that the study of rocket flight is an accepted form of research or experimentation. In some respects, however, the situation is a better one than that of the early pioneer days in aviation. So many marvels have intervened that the world does not question revolutionary advances so sceptically.

At present it is generally accepted that the rocket is an excellent method for investigating the higher regions of the stratosphere, and that it may bring much valuable information in meteorology and in the properties of cosmic rays. The carrying of mail or passengers by rockets seems far off. Interplanetary flight, while it is, academically considered, possible, may be regarded as still further away. The subject, however, is no longer a fantastic one and a great many members of the general public and no doubt a good many technicians are interested in learning what there is in the art of the rocket, its difficulties, and possibilities.

To any such readers seeking an introduction to the subject, P. E. Cleator's "Rockets Through Space" can be highly recommended. The book is written in a clear fascinating style and if it does err on the imaginative side, it is nevertheless entirely sound in its technical information.

[1] Professor of aeronautical engineering, in charge of the Daniel Guggenheim School of Aeronautics, New York University, New York, N. Y. Mem. A.S.M.E.

The book begins with a chapter entitled "Interplanetary Ideas" and postulates the requirements of a vessel intended to travel through space with a graceful analogy to the work of Columbus. Then follows the evolution of the rocket motor beginning with powder rockets such as those used on the von Opel rocket cars. Powder has, according to the author, serious objections, the chief of which are its dangerous nature and insufficiency of power.

One of the first serious steps undertaken in rocket motors was in the construction of the Mirak rocket by the German Society for Space Navigation. Here the principles of the rocket were developed with liquid oxygen, a gasoline container, a carbon-dioxide charger, and a combustion chamber lined with ceramic material as the main elements. Short successful flights were made in 1930, although the experimentation was marred by the death of Dr. Paul Heylandt on May 17, 1930, and there seems to be no question that liquid oxygen and gasoline seem to form the right method of approach at present.

The rocket depends on its action in recoil and it is obvious that the velocity of the exhaust gases should be as high as possible. It is theoretically possible to obtain an exhaust velocity of 9100 fps. Dr. Goddard has actually secured a velocity of 7872 fps which represents a velocity efficiency of some 70 per cent. The unfortunate part is that only when the velocity of the vessel itself is high that such velocity of jet reaction is efficient. In the von Opel experiments with cars 95 per cent of the fuel energy was wasted because of the slowness of the cars. Mr. Cleator indicates that with a proper combination of fuels it should be possible, by burning up the bulk of the fuel at the onset of the journey, to start a rocket on its interplanetary flight. Interesting calculations are given showing that no less than 4380 tons of fuel would be required to transport 20 tons of rocket, passengers, and equipment into space. Something like $100,000,000 would be required for the experiment. Other difficulties in interplanetary flight are interestingly discussed. Extremes of tempera ture have to be met, the state of weightlessness between planets will have to be overcome by artificial gravitation. The problems of extra-terrestrial navigation obviously offer many difficulties. The author has prepared an interesting diagram of the course of the space ship from the earth to the moon which seems quite logical. Landings on other planets would not be so easy particularly if greater gravitational pull existed on a planet of greater mass.

This brief review indicates the many difficulties but also the great interest of the subject.

The final portion of the book deals with the position today, shows the details of a variety of rockets used by various societies, and gives descriptions of a number of experiments made. The chapter on "Progress of Tomorrow" reads a little like a moving picture on the order of "Things to Come," with speculations of life on other planets.

Not the least valuable part of the book is the list of references to other works. The engineer turning to this book may not find all the technical information that has already appeared in technical publications and other books, but he may perhaps have his imagination and interest so stimulated as to turn to more serious study of this fascinating subject.

Living Together

Living Together in a Power Age. By Samuel S. Wyer. Association Press, New York, N. Y., 1936. Cloth, $6 \times 9^1/_4$ in., 231 pp., $2.50.

MR. SAMUEL S. WYER, a member of The American Society of Mechanical Engineers, has presented in his book, "Living Together in a Power Age," an interesting mixture of realism and idealism, of facts and opinions. The book may be read with profit and interest by engineers in particular. Any intelligent reader will find in it plenty of facts to enlighten a beclouded mind and easily assimilated statistics which he can use with telling effect because they are so clearly presented.

The criticism, that books on economic and social problems are either highly generalized and dogmatic, if they avoid facts and statistics, or too high-brow and confusing if they are written for specialists and present wearisome statistics, cannot be leveled against Mr. Wyer's presentation. For the statistics are graphically presented—Mr. Wyer has long been known for his ability in this direction—and give a keen edge to short, crisp sentences that, in general, leave the reader in no doubt as to what the author intended them to signify. However, there is plenty of dogmatic assertion in Mr. Wyer's generalizations on social and economic questions, and hence the entire book, including its facts and statistics, must be viewed as a case for the author's personal views and philosophy. Any reader can assent to many statements only to find himself disagreeing with others in the same context. But this is hardly the author's fault, for on the subjects with which he is concerned there are as many views as there are men.

"We need a living-together philosophy, Mr. Wyer explains in his opening chapter, "resting on the wise use of what the engineer has made possible, and an understanding of human welfare and the will to make this the sole justification for our economic activities. Power—which is the rate of doing work—is

the new idea in today's economic muddle." Hence, the title of the book.

To provide a background for his book, Mr. Wyer has included a first chapter entitled "What has happened," which develops briefly what he considers to be the "contributory causes of today's economic muddle." These may be roughly grouped as factors related to wealth and capitalism, the world war, labor, banking and money, the law, religion and emotional thinking, and politics and government. There follow chapters, largely simplified expositions of facts and general knowledge, with charts and graphs for easy understanding, on stored energy, electric power, transportation, agriculture, water resources and control, population problems, government ownership (with an exposure of the Ontario Hydro dogma), and available governmental systems—anarchism, nihilism, syndicalism, socialism, Marxism, communism, fascism, and capitalism.

The tenth chapter is devoted to Mr. Wyer's ideas on "How to make plenty possible for all," and the last chapter to what he calls, "Living-Together Planning," for which he offers a Constitutional amendment that provides for the establishment of a National Planning Council. At the end is a "New Decalog for Human Welfare."

The book makes interesting reading for political-campaign disputants.—G. A. S.

Books Received in Library

AIR-BRAKE TROUBLES; BRAKE RIGGING. By J. W. Harding. International Textbook Co., Scranton, Pa., 1934. Leather, 5 × 8 in., illus., diagrams, charts, tables, $2.50. A manual of instruction on air-brake troubles and repair; methods of testing; the basic theory of railway brakes.

AUDELS DIESEL ENGINE MANUAL, Questions and Answers. By A. B. Green and R. A. Zoeller. Theodore Audel & Co., New York, 1936. Leather, 5 × 7 in., 292 pp., illus., diagrams, charts, tables, $2. A catechism covering the theory, operation, and maintenance of Diesel engines in a simple, practical way.

FREIGHT-CAR BRAKE EQUIPMENT. By J. W. Harding. International Textbook Co., Scranton, Pa., 1935. Leather, 5 × 8 in., illus., diagrams, tables, $1.70. This volume describes the two usual types of air brakes for freight service, and gives directions for operating and maintaining them.

HIGH-SPEED DIESEL ENGINES FOR Automotive, Aeronautical, Marine, Railroad, and Industrial Use. By P. M. Heldt. Second edition. P. M. Heldt, Nyack, N. Y., 1936. Cloth, 6 × 9 in., 438 pp., illus., diagrams, charts, tables, $4.50. The aim of this work is to present a concise, orderly review of the research work that has been done on problems connected with various phases of the design of automotive-type Diesel engines, accompanied by descriptions of typical examples of the various subclasses. A chapter on oil engines of other types is included. This edition has been largely rewritten and several new chapters added.

HYDROELECTRIC POWER STATIONS. By E. A. Crellin. International Textbook Co., Scranton, Pa., 1935. Leather, 5 × 8 in., illus., diagrams, charts, tables, $1.60. An elementary text on design and construction which treats the subject descriptively.

MACHINE DRAWING FOR STUDENTS. By F. J. Pryer. Sir Isaac Pitman & Sons, London; Pitman Publishing Corporation, New York, 1936. Paper, 7 × 10 in., 141 pp., illus., diagrams, charts, tables, $2. This text is intended for students of aeronautical engineering and the exercises and illustrations are all related to that subject. The course includes the elements of mechanical drawing and freehand sketching. The technique of the British Standards Institution is followed. The course will fill the chief aim, which is to teach the student how to read drawings.

MAINTENANCE OF TRACK. By E. E. R. Tratman, A. De Groot, and F. A. Cox. International Textbook Co., Scranton, Pa., 1934. Leather, 5 × 8 in., illus., diagrams, tables, $1.25. A textbook for track foremen, giving practical directions for trackwork of all kinds. A section on string lining of track is included.

MODERN GLASS PRACTICE. By S. R. Scholes. Industrial Publications, Chicago, 1935. Cloth, 6 × 9 in., 344 pp., illus., diagrams, charts, tables, 9 × 6 in., cloth, $6. This volume provides a concise, yet comprehensive account of modern methods of glass making. The book is intended primarily for students of glass technology, but will also be of use to glass makers and others who wish a general account of current practice.

PSYCHOLOGY OF HUMAN RELATIONS FOR EXECUTIVES. By J. L. Rosenstein. McGraw-Hill Book Co., New York and London, 1936. Cloth, 5 × 8 in., 284 pp., $2.50. This book is intended to give executives an understanding of the workers whom they lead and supervise, in order that they may develop better techniques for dealing with them. The reasons for human behavior, the ways in which individuals face difficulties, personality, the kinds of workers, cooperation, discipline, and similar topics are discussed practically and helpfully, on the basis of the author's experience as consulting psychologist to a prominent manufacturer.

ROYAL TECHNICAL COLLEGE JOURNAL, vol. 3, part 4, January, 1936. Paper, 7 × 10 in., pp. 531–698. Royal Technical College, Glasgow, Scotland. Paper, 7 × 10 in., illus., diagrams, charts, tables, 10s 6d. This publication is a record of research work carried out recently in the College. Papers of special interest to engineers include: Influence of annealing and overstrain on notched-bar bend tests of longitudinal and transverse specimens; small-scale measurement of sound transmissions; the conductivity of a freshly broken glass surface; the thermal diagram for the system FeS–Cu_2S; load partition in multirow joints; and direct and bending stresses in hemispherical dished ends.

TEXTBOOK OF THE MATERIALS OF ENGINEERING. By H. F. Moore; with a chapter on Concrete by H. F. Gonnerman; and a chapter on the Crystalline Structure of Metals, by J. O. Draffin. Fifth edition. McGraw-Hill Book Co., New York and London, 1936. Cloth, 6 × 9 in., 419 pp., illus., diagrams, charts, tables, $4. The physical properties of the common materials used in structures and machines, together with descriptions of their manufacture and fabrication, are presented concisely in suitable form for use as a college textbook. The new edition has an added chapter on failure by corrosion and wear, the chapter on failure by "creep" has been largely rewritten and revisions and additions have been made throughout the book.

THÉORIE ET TECHNOLOGIE DES ENGRENAGES. Vol. 3, Les Transmissions par Engrenages. By J. Pérignon. Dunod, Paris, 1936. Cloth and paper, 6 × 10 in., 78 pp., illus., diagrams, charts, tables, cloth, 28 fr.; paper, 19 fr. The final volume of this work on gearing treats briefly and practically of transmission gearing. The statics and dynamics of the subjects are discussed. A chapter is devoted to gearing for electric locomotives and another to reducing gearing for ships.

WÄRMETECHNISCHE ARBEITMAPPE, gesammelte Arbeitblätter aus den letzten Jahrgängen von "Archiv für Wärmewirtschaft und Dampfkesselwesen." Ergänzungslieferung. V.D.I. Verlag, Berlin. Paper, 9 × 12 in., 44 pp., charts, 4.40 rm. In order to provide the operating engineer and designer of power plants with a convenient working collection of the practical diagrams that had appeared in the *Archiv für Wärmewirtschaft und Dampfkesselwesen*, a collection of these, enlarged in scale and in loose-leaf form, was published about two years ago. The present collection supplements that publication by adding 44 new charts. These relate to problems in fuels, feed water, firing, steam turbines, internal-combustion engines, heating, steam distribution, etc. They provide simple, graphical solutions for many recurrent calculations.

DIE WÄRMEÜBERTRAGUNG. By M. ten Bosch. Third edition. Julius Springer, Berlin, 1936. Cloth, 6 × 10 in., 282 pp., illus., diagrams, charts, tables, 26.70 rm. In preparing a new edition of his work, Professor ten Bosch has incorporated the results of recent studies of heat transmission, and made some extensions of the book. It is intended both as a textbook and reference work, designed upon severely practical lines, to give the practicing engineer the necessary numerical data for the design of heat-exchange apparatus. A bibliography is included.

JAMES WATT, Craftsman and Engineer. By H. W. Dickinson. Cambridge University Press, London; The Macmillan Co., New York, 1936. Cloth, 6 × 10 in., 207 pp., illus., diagrams, $4. The author of this work, in collaboration with Rhys Jenkins, prepared the Watt Memorial volume, "James Watt and the Steam Engine," issued in 1927 to commemorate the centenary of Watt's death. The present work is intended for the general reader who is more interested in the life and work of Watt than in the development of the steam engine. Mr. Dickinson has written an interesting, readable account of Watt's career, based on intimate knowledge, which can be warmly recommended.

WERKZEUGE UND PRESSEN DER STANZEREI. Part 2: Pressen. By E. Göhre. V.D.I. Verlag, Berlin, 1936. Paper, 6 × 8 in., 86 pp., illus., diagrams, charts, tables, 5.40 rm. The second volume of this manual of presswork is devoted to presses. A concise, yet comprehensive description of the various types of presses is given, with comments on their suitability for different purposes, power requirements, etc. A large number of photographs and drawings illustrate the book. A brief chapter on shears is included. The book is intended as a guide for the user.

WHAT'S GOING ON

Including News of A.S.M.E. Affairs

This Month's Authors

FEW engineers have shown a livelier concern for the implied responsibility of the engineer to society for his "brain children," i.e., his inventions and industrial organizations, than C. F. HIRSHFELD, whose contributions on this subject frequently appear in these pages. Readers will recall his recent paper on social security. This month's contribution by Mr. Hirshfeld stresses the fact that experimentation in social problems must be approached with a different technique from that employed in an engineering laboratory, and that history provides a most useful guide in understanding the effects of social change.

Mr. Hirshfeld is well known to engineers as the director of research of the Detroit Edison Company, as a member of The American Society of Mechanical Engineers active in the work of its technical and administrative committees, and as first chairman of the Engineers' Council for Professional Development, an organization which he cites, in this month's paper, as an example of one approach which engineers have attempted to improve the engineering professional status and to broaden the engineering viewpoint as well as its influence.

VLADIMIR KARAPETOFF, professor of electrical engineering at Cornell University since 1904, consulting engineer, inventor, musician, and author of engineering books and papers, is a native of Russia, where he received his early education and did his first engineering and teaching work in electrical engineering and hydraulics. He also studied at Darmstadt, Germany. He came to this country as an employee of the Westinghouse Electric and Manufacturing Company in 1902. The Franklin Institute awarded him the Montefiore prize in 1923, and the Elliot Cresson Medal in 1927. He is a member of numerous engineering, scientific, and honorary societies. From 1917 to 1926 he was research editor of the *Electrical World*. His musical accomplishments have brought him distinction and public notice through public recitals on the pianoforte and on the five-stringed cello which he developed.

Professor Karapetoff's paper in this issue, which is a companion to one that appeared in MECHANICAL ENGINEERING in 1933, applies the statistical method to the fundamentals of heat radiation.

Increased use of high-pressure steam has resulted in studies in the thermodynamics of water at high pressure and temperature. Several such studies have been reported in MECHANICAL ENGINEERING, and this month Messrs. Stuart and Yarnall contribute one on the flow through two orifices in series.

MILTON C. STUART, professor of mechanical engineering, Lehigh University, Bethlehem, Pa., member, A.S.M.E., was graduated from the University of Pennsylvania in 1909, with the degree of B.S. in Mechanical Engineering. In 1926 he received the degree of M.E. from the same institution. Professor Stuart has devoted his career largely to education and research, with the exception of a period spent with the Cambria Steel Company as assistant steam engineer. He has taught at Rensselaer Polytechnic Institute, and has served as mechanical engineer at the U. S. Naval Experiment Station, Annapolis, Md. Since 1926 he has been at Lehigh University.

D. ROBERT YARNALL, coauthor with Professor Stuart, is cofounder and mechanical engineer of Yarnall-Waring Co., Philadelphia, Pa., manufacturers of power-plant equipment. He was graduated in 1901 from the University of Pennsylvania with B.S. in Mechanical Engineering. In 1905 he received the degree of M.E. from the same university. Several years ago he designed for the Yarnall-Waring Co. a high-pressure steam laboratory, described in MECHANICAL ENGINEERING in the issue of December, 1931. As a member of the A.S.M.E. he served the Council in the capacity of manager from 1917 to 1920. He is a director and vice-president of the Engineering Foundation and a member of the Board of the United Engineering Trustees.

MAX M. FROCHT, who writes on "Photoelastic Studies in Stress Concentration," received the degree of B.S. in mechanical engineering in 1922 and of Ph.D. in engineering mechanics in 1931, both from the University of Michigan. From 1912 to 1920 he was associated with various automobile concerns, including the General Motors Research Laboratories at Dayton, Ohio. He has been a member of the faculty of The Carnegie Institute of Technology since 1922 and he now holds the position of associate professor of mechanics. During a leave of absence in 1930 he made a study of the organizational structure of the Ford Motor Company for the Autostroy, a U.S.S.R. corporation. Since 1931 he has been engaged in photoelastic research.

Two authors this month contribute their views on the important managerial problem of machine interference, and a third comments on them. W. R. WRIGHT, who is associated with Stevenson, Jordan, and Harrison, management engineers, of New York, N. Y., was graduated from the University of Michigan with the degree of B.S. in mechanical and industrial engineering. He has served with the Western Electric Company in work involving time standards, labor grading, and wage-incentive methods and, prior to taking his present position, was associated with Geo. D. Penniman, Jr., and Associates, Baltimore, Md.

WILLIAM G. DUVALL, who is a member of the piece-rates division of the Western Electric Company at the Point Breeze Works, Baltimore, Md., was graduated in 1930 from Washington College, Chestertown, Md., with the degree of B.S. in mathematics and physics. After one year spent as assistant to the comptroller of the Baltimore Enamel and Novelty Co., Mr. Duvall took up his present work, which consists in establishing piece rates and standard-time data and studies with a view to subjecting as much as possible of the information relating to his work to mathematical formulation.

HAROLD FREEMAN, who comments on the contributions by W. R. Wright and William G. Duvall, is a member of the department of economics, Massachusetts Institute of Technology, a specialist in statistical technique and the theory of probability.

EDWIN S. BURDELL is associate professor of Sociology at the Massachusetts Institute of Technology.

Opportunity for Young Engineers in U. S. Navy

A COMMUNICATION from Captain Walter H. Allen (CEC), U.S.N., Bureau of Yards and Docks, Washington, D. C., announces that the Navy contemplates filling by candidates from civil life, existing vacancies in the Corps of Civil Engineers of the regular Navy. Examinations of candidates are to be held shortly.

This is the first time since 1925 that opportunity has been offered to those not graduates of Annapolis to enter the Civil Engineer Corps. The greatly increased work and responsibilities of the civil engineers of the Navy necessitate an immediate increase, and it is entirely probable that from 10 to 15 young men will be commissioned as Lieutenants (Junior Grade) in the Corps within the next year.

Engineers, between the ages of 22 and 30, wishing to know more about the requirements with a view to taking the examinations and becoming candidates for the proposed appointments should communicate at once with Captain Allen, requesting a copy of "Announcement of Examination for Appointment as Assistant Civil Engineer, with the rank of Lieutenant (Junior Grade), United States Navy." The document bears the designation N. Nav. 485 (June, 1936). According to the announcement, papers covering preliminary examinations as to general fitness must be submitted by candidates before Sept. 15, 1936.

Nominated for

A.S.M.E. OFFICERS IN 1936-1937

For President

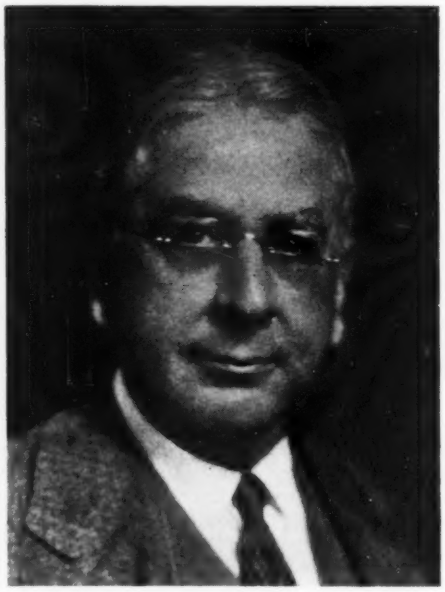
JAMES H. HERRON

For Vice-Presidents

R. J. S. PIGOTT

J. M. TODD

J. A. HALL



JAMES H. HERRON

For Managers

S. W. DUDLEY

K. H. CONDIT

E. W. BURBANK

Biographical sketches of the candidates will be found on pages 527–529 of this issue.

REGINALD J. S. PIGOTT

JAMES M. TODD

JAMES A. HALL

SAMUEL W. DUDLEY

KENNETH H. CONDIT

EDWARD W. BURBANK

Nominations for Officers of A.S.M.E., 1936–1937

AT THE Semi-Annual Meeting of The American Society of Mechanical Engineers, Dallas, Texas, June 15–20, 1936, James H. Herron, president, The James H. Herron Company, of Cleveland, Ohio, and at present vice-president of the Society, was nominated President of the Society.

Vice-presidents nominated to serve on the Council of the Society were James M. Todd, consulting mechanical and electrical engineer, of New Orleans, La., at present a manager of the Society; James A. Hall, professor of mechanical engineering at Brown University, Providence, also a manager of the Society; and R. J. S. Pigott, staff engineer in charge of engineering, Gulf Research and Development Corporation, Pittsburgh, Pa., and chairman of the Society's Special Research Committee on Fluid Meters.

Nominations for members of the Council to serve as managers were: Kenneth H. Condit, editor, *American Machinist*, McGraw-Hill Publishing Co., New York, N. Y., chairman of the Society's Committee on Professional Divisions; E. W. Burbank, Dallas, District Manager, Allis-Chalmers Mfg. Co., Dallas, Texas, chairman of the Society's Committee on Relations With Colleges; and S. W. Dudley, newly appointed dean of the Yale School of Engineering, Strathcona Professor of Mechanical Engineering, Yale University, New Haven, Conn., and chairman of the Society's Committee on Publications.

The National Nominating Committee for 1936 which reported the nominations consists of H. Diederichs, Ithaca, N. Y., chairman, with V. M. Palmer, Rochester, N. Y., and F. M. Feiker, Washington, D. C., alternates; Edwards R. Fish, Hartford, Conn., with Charles M. Allen, Worcester, Mass., and G. E. Hulse, New Haven, Conn., alternates; J. N. Landis, Brooklyn, N. Y., with W. E. Caldwell, New York, N. Y., and F. M. Gibson, Brooklyn, N. Y., alternates; R. P. Kolb, University, Ala., with B. E. Short, Austin, Texas, alternate; F. W. Marquis, Columbus, Ohio, with George W. Bach, Erie, Pa., and L. E. Jermy, Cleveland, Ohio, alternates; Fred H. Dorner, Milwaukee, Wis., with R. M. Boyles, St. Louis, Mo., alternate; and W. J. Cope, Salt Lake City, Utah.

Biographical sketches of the nominees, who will be voted upon by letter ballot during the fall, follow:

James H. Herron

JAMES H. HERRON, nominated for the office of President of The American Society of Mechanical Engineers, is president of The James H. Herron Company, Cleveland, Ohio. He was born in Girard, Pa., on January 4, 1875. In 1909 he received the degree of B.S. in mechanical engineering from the University of Michigan.

From 1889 to 1895 he served as an apprentice with the Sterns Manufacturing Company, Erie, Pa. From 1895 to 1909 he was engaged in engineering work in the following capacities: Assistant and chief engineer, the Erie City Iron Works, Erie, Pa.; assistant engineer, The Cambria Steel Company, Johnstown, Pa.; vice-president and chief engineer, The Bury Compressor Company, Erie, Pa.; manager, Motch and Merryweather Machinery Company, Detroit, Mich.; and works manager and chief engineer, the Detroit Steel Products Company, Detroit, Mich. Since 1909 he has been president of The James H. Herron Company, engineers and chemists, of Cleveland, Ohio. In addition he is president of the Paragon Laboratories, director of the Baldwin Farms Land Company, and secretary of the National Engineering Inspection Association.

Mr. Herron is the inventor of the air-compressor inlet-valve unloader and of numerous devices for use with air compressors and metallurgical furnaces. He is the author of articles on metallurgical subjects published in technical periodicals, and was an associate editor of Hool and Johnson's "Handbook of Building Construction" and Hool and Kinne's "Structural Engineers' Handbook Library."

As a member of The American Society of Mechanical Engineers, he served on the Committee on Local Sections from 1917 to 1922, and was a member of the Council from 1922 to 1925. During all of that time, and since, he has been active in the work of the Cleveland Section. He is a representative of the Society on the Bureau of Registration of the National Council of State Boards of Engineering Examiners, and a member of the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, the American Institute of Electrical Engineers, the American Chemical Society, the American Society for Testing Materials, the British Iron and Steel Institute, the Society of Automotive Engineers, the American Concrete Institute, the Cleveland Engineering Society, of which he was president, 1917–1918, and a fellow of the American Association for the Advancement of Science. His civic services have included the presidency of the Cleveland Heights Board of Education as well as directorship in the engineering division of the Cleveland War Industries Board and the Municipal Research Bureau of Cleveland. He is a member of the Committee on Professional Conduct of the A.S.M.E., chairman of its Committee on Registration, and chairman of the Advisory Board on Professional Status. In 1934 he was elected vice-president of the Society.

James M. Todd

JAMES M. TODD, nominated for the office of Vice-President of The American Society of Mechanical Engineers, is engaged in the private practice of consulting mechanical and electrical engineering, New Orleans, La. He was born in 1896 in Franklin, La. He was graduated from Tulane University in 1918 with the degree of bachelor of engineering, and in 1930 received the degree of mechanical engineer. During the World War, Mr. Todd served as a lieutenant of engineers, seeing service in England and France. After the war he became chief engineer for Penick & Ford, Ltd., formerly of New Orleans, and now of Cedar Rapids, Iowa. From 1921 to 1928 he was associated as assistant engineer with A. M. Lockett & Company, mechanical engineering contractors, New Orleans, resigning to engage in private practice of consulting mechanical and electrical engineering. He has since been retained as consultant in mechanical and electrical problems by the Orleans Parish School Board, the Board of State Engineers, the City of New Orleans, and Tulane University. He has had a wide experience in the mechanical and electrical equipment of buildings and industrial plants.

Mr. Todd became a junior member of the Society in 1922 and a member in 1929. In 1934 he was elected a manager of the Society. He served two terms as chairman of the Committee on Local Sections, was a member of the Committee on Registration of Engineers, and of the Committee on the Economic Status of the Engineer. He is a past-president of the Louisiana Engineering Society and a member of the American Institute of Electrical Engineers.

James A. Hall

JAMES A. HALL, nominated for the office of Vice-President of The American Society of Mechanical Engineers, is professor of mechanical engineering at Brown University. Born in Berlin, Vermont, in 1888, he attended the public schools of Providence and was graduated from Brown University in 1908 with the degree of A.B. He received the degree of bachelor of science in mechanical engineering from the same institution in 1910, remaining as assistant and then instructor in mechanical engineering until 1914, when he became connected with the engineering department of the Link-Belt Company in Philadelphia. The following year he returned to Brown University as assistant professor of mechanical engineering, teaching courses in machine design and industrial management. He became associate professor in 1920, and since 1925 has been professor of mechanical engineering. Professor Hall has also carried on a consulting-engineering practice, and since 1926 has been associated with the Brown & Sharpe Manufacturing Company in Providence, R. I., as consulting engineer.

Professor Hall joined the Society in 1912. He was chairman of the Providence Section of the Society in 1922, and a member of the Committee on Local Sections from 1922 to 1926, being chairman the last year. He was a member of the Research Committee on the Cutting and Forming of Metals from 1924 to 1930, and chairman from 1925 to 1927. He was chairman of the Nominating Committee of the Society in 1929, and a member of the Committee on Constitution and By-Laws 1931 to 1933. In 1933 he was elected manager of the A.S.M.E. and has served on the Executive Committee of the Council since that time. At present he is chairman of the Machine Design Committee of the Society's Machine Shop Practice Division. Professor Hall is a past-president of the Providence Engineering Society, past-chairman of the New Eng-

land Section of the S.P.E.E., a member of the Newcomen Society, of the Society of Sigma Xi and fellow of the American Association for the Advancement of Science. He is the author of numerous articles published in the technical press.

R. J. S. Pigott

R. J. S. PIGOTT, nominated for the office of Vice-President of The American Society of Mechanical Engineers, is staff engineer, Gulf Research Laboratory, Pittsburgh, Pa.

Mr. Pigott was born in Shropshire, England, in February, 1886. He was graduated from Columbia University in 1906 with the degree of M.E., and went to work with the Interborough Rapid Transit Co., New York, N. Y., as assistant engineer and, after the first year, as chief draftsman in the motive-power department in charge of design of low-pressure turbines, and as assistant engineer in charge of construction and tests. From 1911 there followed two years, one spent as superintendent of construction of the New England Engineering Co., New York, N. Y., and the other as assistant professor of steam engineering at Columbia University.

In July, 1913, Mr. Pigott returned to the Interborough as construction engineer in charge of all design and construction. During the three years of this period of service he designed, installed, and tested three 30,000-kw turbines at the 74th Street station. In 1915 he became consulting engineer for the Remington Arms U.M.C. Co., Bridgeport, Conn. He was district engineer, Riley Stoker Co., 1917; superintendent, raw-materials department, Bridgeport Brass Co., Bridgeport, Conn., 1917 to 1920; works manager, Crosby Steam Gage and Valve Co., Boston, Mass., 1920 to 1922; mechanical engineer, Stevens and Wood, Inc., 1922 to 1925 and 1928 to 1929; and consulting mechanical engineer, Public Service Production Company, Newark, N. J., from 1925 to 1928. He accepted his present position as staff engineer, Gulf Research Laboratory, in 1929.

Mr. Pigott holds a number of patents on power machinery and equipment and is the author of numerous papers. He is a member of the S.A.E., A.G.A., and the American Petroleum Institute. He became a junior member of the A.S.M.E. in 1912, an associate-member in 1913, and a member in 1918. His service to the A.S.M.E. has covered much of the period of his membership. Among other services he is at present advisory member of the Committee on Research; chairman of the Special Research Committee on Fluid Meters; member of the Special Research Committee on the Thermal Properties of Steam; member of the Power Test Code Main Committee, chairman of its Committee No. 2 on Definitions and Values, and member of its Committee No. 19 on Instruments and Apparatus; member of the Committee on Radiant Heat in Boiler Furnaces; and member of the A.S.A. Sectional Committee on Scientific and Engineering Symbols and Abbreviations, and member of Subcommittee on Research in Industrial Aerodynamics.

Kenneth H. Condit

KENNETH H. CONDIT, nominated for the office of Manager of The American Society of Mechanical Engineers, is editor of the *American Machinist*, McGraw-Hill Publishing Company, New York, N. Y. Mr. Condit is just completing a term of service on the Committe on Professional Divisions, prior to which, from 1923 to 1928, he was a member of the Committee on Publications, and from 1928 to 1933, a member of the Committee on Awards.

Mr. Condit was born at East Orange, N. J., on March 1, 1888. He was educated in the schools of that town and was graduated from Stevens Institute of Technology in 1908 with the degree of mechanical engineer. He commenced his engineering work in the Safety Car Heating & Lighting Co. as a draftsman and assistant engineer. Ill health made desirable a change to work that would provide more outdoor employment, so Mr. Condit, in 1910, accepted a position with the Newark Branch of A. G. Spalding & Bros., at that time agents for the Stevens Duryea automobile, and later with the White Motor Co., in order to become familiar with motor-truck problems.

In 1911 it became possible for Mr. Condit to renew his educational career by taking courses in civil engineering at Columbia University, where he spent one term, and at Princeton, from which he received the degree of civil engineer in 1913.

As the result of the offer of an instructorship in engineering at Princeton, Mr. Condit continued at the University from 1913 to 1917 in charge of the materials-testing laboratory and engaged in teaching a number of engineering subjects. On July 5, 1917, he was commissioned first lieutenant in the aviation section of the signal corps. With two other members of the Princeton faculty he organized the Princeton School of Military Aeronautics and was placed in charge of the engine department. In September, 1918, he was promoted to a captaincy and transferred to Wright Field, Dayton, where he remained until after the Armistice.

Mr. Condit became associate editor of the *American Machinist* in January, 1919. He was made managing editor late in December of the same year, and became editor in 1920. In 1929 he started *Product Engineering*, serving as editor until 1935 when he became consulting editor.

He joined the A.S.M.E. in 1921 and has been actively engaged in its activities ever since. In addition to his periods of service on administrative committees, Mr. Condit served the Machine Shop Practice Division as its secretary in 1923, and as a member of its executive committees several years later.

He is a member of the A.S.A. Sectional Committee on Scientific and Engineering Symbols and Abbreviations; Special A.S.A. Committee on Preferred Numbers; and member of the Special Research Committee on Cutting of Metals, Subcommittee on Metal Cutting Data. He represents the A.S.M.E. on the Gantt Medal Board and is a member of the Committee on Medals.

He has served as secretary and president of the Princeton Engineering Association, and is now chairman of its Committee on Education. He is now secretary of the Princeton Geological Association. He has also served as secretary of the National Conference of Business Paper Editors, and as a member of the Mechanical Advisory Board of the Museum of Science and Industry, New York, N. Y.

Edward W. Burbank

EDWARD W. BURBANK, nominated for the office of Manager of The American Society of Mechanical Engineers, is Dallas District Manager, Dallas, Texas, of the Allis Chalmers Manufacturing Company, with which company he has been connected for the past 25 years. He is chairman of the Committee on Relations With Colleges of the A.S.M.E.

Mr. Burbank was born in Sunbury, Ohio, on February 15, 1889. He was educated at Tulane University, New Orleans, from which he was graduated in 1911 with a degree of B.E. in mechanical and electrical engineering. Following graduation Mr. Burbank spent two years as a student apprentice in the shops of the Allis-Chalmers Manufacturing Company, Milwaukee, Wis. For the next three years he was engaged in the experimental design and development of hydraulic machinery and in conducting extensive tests on this type of equipment.

In 1916 Mr. Burbank was transferred to the sales department of the Allis-Chalmers Company and was sent to the New Orleans office of the Company, where he remained five years in the position of sales engineer. In 1921 he was transferred to Dallas, Texas, and became Dallas district manager.

Mr. Burbank was elected associate member of the A.S.M.E. in 1919 and was transferred to member in 1921. He is a member of the A.I.E.E., Dallas Technical Club, and the American Petroleum Institute. He has been active in A.S.M.E. affairs in Dallas and was responsible for the formation of the North Texas Section. He has actively served the Society for fifteen years and recently, as general chairman of the Dallas Committees, arranged the Semi-Annual Meeting held in June, 1936.

S. W. Dudley

SAMUEL WILLIAM DUDLEY, dean of the Yale School of Engineering and Strathcona Professor of Mechanical Engineering, Yale University, New Haven, Conn., has been nominated for the office of Manager of The American Society of Mechanical Engineers.

Mr. Dudley was born in Westville, Conn., October 18, 1879. He was graduated from the Sheffield Scientific School, Yale University, in 1900 with the degree of Ph.B., and in 1903 he received the degree of M.E. from the same institution. From 1900 to 1905 he taught engineering and mathematical subjects at Yale, with periods of service during the summer at the Winchester Repeating Arms Co., New Haven, Conn., and the Westing-

house Air Brake Company, Wilmerding, Pa. From July, 1905, to September, 1906, he worked in the test department of the Westinghouse Air Brake Co., and during the following year he was transferred to their New York office as mechanical expert to supervise the new air-brake installations during the inauguration of the N.Y.C. and the N.Y.,N.H.&H. electrification. In July, 1907, he returned to Wilmerding where he continued until 1921, rising to the position of chief engineer of the Air Brake Company. During that time he was actively engaged in improvements in air brakes and in many notable tests of air-brake equipment. He has written extensively on the theory and practice of air-brake engineering.

In 1921 Mr. Dudley became Strathcona Professor of Mechanical Engineering at Yale University, where, in 1923, he succeeded Prof. L. P. Breckenridge as chairman of that department in the Sheffield Scientific School. In 1936 he was appointed dean of the Yale School of Engineering, which had been formed by a separation of the engineering departments of the University from the Sheffield Scientific School.

Mr. Dudley became a junior member of the A.S.M.E. in 1904 and was transferred to the grade of member in 1916. He has been active in the work of the Society in New Haven and on administrative committees. He has served as secretary-treasurer and as chairman of the New Haven Section of the Society and as honorary chairman of the student branch at Yale University. In 1931 he was guest of honor at a dinner in New Haven in recognition of his services to the Society in conducting the New Haven Machine Tool Exhibition which, for several years, had been a joint enterprise of the Society's New Haven Section, the Chamber of Commerce of New Haven, and Yale University. He was chairman of the A.S.M.E. Committee on Meetings and Program at the time of the Society's Fiftieth Anniversary in 1930 and is present chairman of the Committee on Publications.

Applied Mechanics Meeting, Pittsburgh, Pa., June 11–13

With a registration of 125 drawn from all parts of the country, the Applied Mechanics Division of The American Society of Mechanical Engineers held its fourth National Meeting at the Carnegie Institute of Technology, Pittsburgh, Pa., June 11–13, in coöperation with the Pittsburgh Section of the Society and Carnegie Institute of Technology.

In four sessions, one each on Thursday and Friday morning and Saturday morning and afternoon, a technical program of sixteen papers and a general discussion on creep of metals was successfully completed, although a few of the papers were read by title only.

On Thursday afternoon members and guests visited the research laboratories of the Aluminum Company of America, and on Friday afternoon the Westinghouse Research Laboratory and the Gulf Research Laboratory.

In commemoration of the 200th anniversary of the birth of the eminent scientist, Charles Augustin de Coulomb (June 11, 1736), Prof. S. C. Hollister, of Cornell University, delivered an address at the annual dinner, Friday evening, entitled "The Scientific Studies of Coulomb."

The committee in charge of the meeting consisted of M. M. Frocht and R. E. Peterson, cochairman, J. A. Dent, A. V. Karpov, A. Nádái, R. J. S. Pigott, R. L. Templin, K. F. Treschow, M. Stone, and O. R. Wikander.

The papers presented at the meeting, on none of which decision as to publication has been reached, were as follows:

Thermal Stresses in Thin Cylinders Due to Temperature Variation Round the Circumference and Through the Wall, by J. N. Goodier.

Buckling of Compressed Rectangular Plates With Built-in Edges, by J. L. Maulbetsch.

The Behavior of Rectangular Flat Plates Under Concentrated Loads, by R. G. Sturm and R. L. Moore.

Cantilever Plate With Concentrated Edge Load, by D. L. Holl (by title).

The Torsionless Bending of a Hollow Beam by a Transverse Load, by W. L. Schwalbe (by title).

Stability of Rectangular Plates Under Shear and Bending Forces, by S. Way (by title).

Plastically Prestressing the Region About a Hole in a Plate, by S. C. Hollister.

The Creep of Metals. Informal discussion of the problem of creep, particularly under combined stress. The discussion was introduced by C. R. Soderberg and Joseph Marin.

Stresses in a Hemispherical Shell Due to Restraint at the Edge, by S. C. Hollister (by title).

Vibration Reduction at Critical Speeds, by C. Cordia and A. L. Kimball.

Forced Vibration in Nonlinear Systems With Various Combinations of Linear Springs, by J. P. Den Hartog and R. M. Heiles.

Criteria for Stability of Vibrating Systems, by S. J. Mikina and J. G. Baker.

Theoretical and Experimental Investigation of the Vibration of Turbine Foundations, by S. Vesselowsky.

An Electrical-Resistance Method of Determining the Mean Surface Temperatures of Tubes, by John H. Marchant.

An Analysis of Journal Bearings of Finite Length, by E. O. Waters.

An Approximate Method for the Determination of Principal Stresses, by Max M. Frocht.

An Efficiency Equation for Gears, by William Howard Clapp (by title).

A.S.M.E. Oil and Gas Power Meeting, Ann Arbor, Mich., June 24–27, 1936

The National Oil and Gas Power Meeting of The American Society of Mechanical Engineers, held at the University of Michigan, Ann Arbor, Mich., June 24–27, attracted an attendance of about 150 engineers representing designers, engine builders, utility companies, industrials, and research groups. The topics discussed covered a wide range.

An informal dinner was given on Wednesday evening, June 24, to honor W. L. Batt president, A.S.M.E., who spent two days at the meeting on his return from the Semi-Annual Meeting of the Society at Dallas, Texas. The technical program included a number of interesting papers by men of authority. There were many interesting discussions. That of F. G. Hechler's paper on Diesel-engineering instruction brought out some disagreement as to the ability of the industry to absorb well-trained Diesel engineers. Mr. Fodor's paper on the spark-ignition oil engine caused comments that the fuel consumption was not favorable nor was output per cubic volume high. The author admitted that Diesels in the field had somewhat better fuel-consumption rates but that the oil engine could be built for a wider range of fuels and built more economically. Mr. Larson's paper on lubricants expressed the opinion that sludging was due to improper combustion and was the engine-builder's problem. Discussion brought out some valuable points on lubrication. The statement was made that railroad four-cycle Diesel switching locomotives required oil change every 200 hr, while others recommended changes every 400 hr; on the Burlington rail trains oil changes are made every 1400 hours.

On Saturday morning the meeting closed with an interesting discussion by E. F. Weber on Diesel-engine applications to railroad locomotives. Mr. Weber discussed frankly the experiences of the Burlington lines including operating information on the use of aluminum pistons.

The A.S.M.E. Oil and Gas Power Division prepared preprints of all papers presented at the meeting. A few extra copies of the preprints are available to members of the Oil and Gas Power Division without charge (except for the Oil Engine Power Cost Report, for which a charge of one dollar is made). The following papers were presented at the meeting:

Diesel Engineering Instruction, F. G. Hechler

Research Activities at University of Michigan, Including Spectroscopic Control in Foundry, Shock-Absorber Lubricants, and Behavior of Metals at High Temperature, A. E. White and C. W. Wood

Fuel-Injection Spark-Ignition Oil Engine, N. Fodor

Bearing Design, Harte Cooke

Engine Governors, G. C. Wilson

Characteristics of A-C Generators for Parallel Operation When Driven by Internal-Combustion Engines, W. T. Berkshire and R. H. Kaufman

Performance of Lubricants Based on Service Conditions, C. M. Larson

Vibration Control of Internal-Combustion-Engine Installations, S. Rosenzweig

History and Present Status of Diesel Fuel-Oil Research and Specifications, A. E. Becker and M. J. Reed

Oil-Engine Power Cost Report

Characteristics of Fuel-Injection Systems, C. R. Alden

Characteristics of Lanova Combustion Systems as Applied to High-Speed Diesels, Hans Fischer

Diesel-Engine Applications to Railroad Locomotives, E. F. Weber

A.S.M.E. Dallas Meeting, June 15–20

MEMBERS of The American Society of Mechanical Engineers from twenty-six states were present at the Semi-Annual Meeting in Dallas, Texas, June 15–20, 1936, and enjoyed the excellent program of entertainment and technical sessions as well as the colorfully illuminated Texas Centennial Exposition. The total registration was 411 members and guests.

Despite its one hundred years of independence, Texas is young industrially. In oil and sulphur, cotton manufacture, and food products, the youth of Texas is marked by a self-confident lustiness that promises success in the future. This spirit of self-confidence and of faith in the future of Southern industry was everywhere manifest in the meetings in the city and at the Exposition.

COMMITTEE AND COUNCIL MEETINGS

June 14, the day before the meeting, two committees met in all-day session—the Committees on Local Sections and on Relations With Colleges, concerned, respectively, with the administration of the local sections and student branches. The Sections Committee devoted a substantial amount of time to the problem of junior organizations in the sections, and were substantially encouraged to learn that 27 sections have active junior organizations. The work of the student branches is also being carried on with a uniformly high degree of success. The new scheme of student-branch operation initiated in 1931 is now in complete operation for the second full year. Ten splendid student conferences were held during April and May and general enthusiasm in the student work is reported.

The Council met all day on June 15, with time out for lunch with the Kiwanis and Technical Clubs of Dallas and for the business session right after dinner. The Council meeting is reported in detail on pages 531 to 532.

Detroit, Mich., was announced at the business session as the meeting place for the 1937 Semi-Annual Meeting. The Constitution and By-Laws Committee, H. H. Snelling, chairman, also presented informally some changes in the Constitution designed to make this document more consistent throughout. The changes will be presented again at the Annual Meeting in December and no action was taken at Dallas.

The entertainment events included the luncheon previously mentioned with the Kiwanis and Technical clubs of Dallas. The luncheon on June 17 was addressed by President Batt. A buffet supper on Wednesday evening was followed by a lecture on "The Why of Boulder Dam," by Dr. William Munroe White, of Milwaukee, who spoke from his intimate contact and fascinating experience in the design of the machinery for the Boulder Dam.

The luncheon on Thursday was addressed by George D. Fairtrace, city manager of Ft. Worth, who spoke from a wealth of intimate experience in municipal management. The dinner dance on Thursday was held in the delightful surroundings of the Dallas Country Club and luncheon on Friday was addressed by A. J. Rollins, Director of Public Works, City of Dallas, who dramatized the engineering problems in municipal affairs by a recital of many experiences in securing public acceptance of the engineering solution of city problems.

MANY TECHNICAL PAPERS

The most important technical feature of the meeting was the Calvin W. Rice Lecture by Dr. Hilding Törnebohm on "Modern Tolerance Requirements and Their Scientific Determination" which appeared in the July, 1936, issue of MECHANICAL ENGINEERING. Dr. Törnebohm's lecture was accompanied by a display of a large number of gaging devices. After the presentation the large audience waited to discuss many points with Dr. Törnebohm personally and to view his novel apparatus.

In view of the fact that the meeting was held near the center of the oil production of the country, it was quite fitting that the emphasis of the program should deal with the petroleum industry. Four sessions were devoted to this and related subjects and the papers presented dealt with the immediate problems of petroleum refining and production and aroused a substantial amount of genuine interest.

The Railroad Division sponsored two sessions, one of which developed an exceedingly interesting exchange of experience in the use of railroad lubrication. Power came in for a substantial amount of attention in five sessions in which the utilization of local fuels was discussed and high-pressure operation revealed. Subjects of timely importance in textiles dealt with air conditioning, helium production, the manufacture of carbon black, and the mechanization of New Mexican potash mines; Diesel-engine practice was dealt with in two sessions. The Hydraulic Division fixed its attention on a discussion of irrigation problems.

A large number of ladies attended the meeting and the Dallas Women's Committee was on duty to see that the guests were given every possible attention.

DEAN POTTER'S ADDRESS

Members attending the meeting had an exceptional opportunity to visit the Centennial Exposition, Saturday, June 20, which was set aside as "Engineers' Day," on which were held special exercises under the auspices of all of the engineering groups in Dallas. The address of the day was delivered by Dean A. A. Potter, president of the American Engineering Council, and past-president, A.S.M.E. In his talk Dean Potter paid tribute to the State of Texas and its citizens. He said in part:

> The industrial development of Texas will require much high-grade engineering talent, as will also the needs of the great Commonwealth for more adequate transportation facilities, growth of cities, topographic mapping, and for air conditioning of homes, factories, offices, and public buildings. As the discovery and use of fire have increased the zone of human habitation so will air conditioning make possible many lines of endeavor formerly made difficult by the continuous hot weather in certain sections of Texas.
>
> With all of these incentives, resources, and facilities; with ample capital for expansion and plenty of adaptable labor, all you Texas engineers need is time in which to build your structures of economic success. Admiration for the engineers of the Southwest cannot, however, stop there. You are engineer-citizens interested in those trends in the engineering profession which affect social conditions and public welfare. You have a philosophy fitting your situation but the evidence of your activity along these lines encourages me to submit some of my observations with reference to the engineering profession for your consideration at this time.
>
> It must be realized that civilized man is destined to live and to work in an environment affected to an increasing extent by engineering. By applying science to practical uses the engineer has created, during the past 75 years, where nothing was before, such giant industries as those which manufacture automobiles, radios, refrigerators, airplanes, telephones, talking machines, typewriters, etc., as well as utilities, which have added to human welfare through electric communication, illumination, transportation, heating, water supply, waste disposal, and power production. These new industries and new utilities are engineering creations, not merely developments; these blessings to humanity have not displaced labor, but have added new opportunities for profitable employment to millions of people. The engineer, whose main function in the past has been to make available countless goods and services for the benefit of all, has always been a creator of employment. It is reasonable to expect the engineer to develop new opportunities in the future as he has in the past, creating new industries, new jobs, and new careers.
>
> The engineer has contributed to the general welfare by reducing drudgery, by increasing our material possessions, by providing new modes of transportation and communication, by developing better forms of entertainment, and by raising the general standard of living for the masses of people. By making available more and more goods at lower and lower costs, in relation to our income, the engineer is constantly increasing our ability to purchase the products of industry and to improve our standard of living.
>
> To an increasing extent the members of the engineering profession are now interesting themselves in social welfare, economic readjustment, and good government. It is this interest on the part of the engineer in matters which affect the public that prompted the organization of the American Engineering Council, an agency intended to aid the engineering profession in presenting a united front in matters of interest to our government and to the public.

RESOLUTION OF THANKS

At the final session of the meeting those present expressed by formal resolution a sincere vote of appreciation to all members in Dallas who participated in the splendid evidences of friendship and good will shown in the planning and conduct of the meeting. Thanks and appreciation of the Society were extended to the local committee and to all of the local members who contributed so much of their time and effort to make the meeting a success.

A.S.M.E. Council Actions

ON JUNE 16, 1936, preceding the technical program of the Semi-Annual Meeting at Dallas, Texas, of The American Society of Mechanical Engineers, the Council of the Society held three sessions. There were present, W. L. Batt, president; Roy V. Wright, past-president; Alex D. Bailey, James H. Herron, John A. Hunter, Eugene O'Brien, and William A. Shoudy, vice-presidents; B. M. Brigman, W. Lyle Dudley, James A. Hall, Jiles W. Haney, Walter C. Lindemann, Ernest L. Ohle, and James M. Todd, managers; W. D. Ennis, treasurer; C. E. Davies, secretary; and the following chairmen of administrative committees: K. H. Condit, Professional Divisions; H. Diederichs, Honors and Awards; and H. H. Snelling, Constitution and By-Laws. Upward of a dozen members of the Society were present at various times during the three sessions.

The following actions of general interest were taken:

BUDGET FOR 1936–1937 ADOPTED

In presenting the budget for 1936–1937, President Batt called attention to certain features of it and summarized them as follows:

"The budget for the coming fiscal year has been given a larger amount of preliminary consideration than in several previous years. The Committee on Policies and Budget has devoted three meetings to it. The Finance Committee has considered it twice, and the Executive Committee has considered it at a regular monthly meeting and at a special meeting called for that purpose. While it is disappointing in many respects, particularly in the moderate amount set aside for surplus, the budget does provide for carrying on the activities of the Society substantially at the same rate as the current year.

"In the opinion of the Finance Committee, industrial and engineering activity during the next year does not promise a basis for higher Society income. The income from membership dues and from advertising has been estimated at the same rate as is estimated for the current year. On publication sales, showing promise of an unusual peak this year which may not carry over next year, a reduction of $5000 has been estimated. Student dues are estimated slightly higher. The net effect is that the total budgeted income of $366,060, without initiation fees, is $4662 less than the income estimated for the current year.

"The budget addition to surplus this year is 5 per cent of the gross income, including initiation fees, or a total of $18,803—an amount all too small if the Society is to avoid financing one year's activity from the following year's dues.

"The total expense budget for 1936–1937 is $357,257—$1668 less than for the current year. In the 1936–1937 budget four new items appear:

(1) Retirement of Certificates of Indebtedness, $5000, provision for which was previously made from surplus

(2) Honorarium for our Society counsel, $250

(3) Contractual provision for staff retirement fund from current income, $4080

(4) Necessary provision for the depreciation and renewal fund for the building, $5000.

To help offset these new items, totaling $14,330, the committee expense has been reduced by $6480, largely through reduction in the Employment Service allotment and Council travel, and office expense has been reduced $9208. The budget for printing and distributing publications has been increased $3050, largely because of the imperative need this year for a Membership List.

ESTIMATED INCOME FOR 1936–1937 ADOPTED BY THE COUNCIL OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, JUNE 16, 1936

Income	Actual 1934–1935	Revised budget 1935–1936	Budget 1936–1937
Initiation fees (to surplus)	$ 15,800.23	$ 10,000.00	$ 10,000.00
Membership dues	$201,660.34	$195,000.00	$195,000.00
Student dues	9,738.50	11,330.00	12,000.00
Interest and discount	11,871.06	11,250.00	10,000.00
MECHANICAL ENGINEERING, advertising	53,503.64	60,500.00	61,500.00
Mechanical Catalog	42,258.15	42,500.00	42,500.00
Publication sales	47,712.06	50,000.00	45,000.00
Miscellaneous sales	1,440.25	1,450.00	1,450.00
Journal of Applied Mechanics	1,531.00	515.00	....
Technical committee contributions	400.00	....	....
Contributions	23.00	369.00	370.00
Registration fees	....	245.00	240.00
Sales of equipment	1,293.00	63.00	....
Subtotal	$371,431.00	$373,222.00	$368,060.00
Bad debts	3,466.97	2,500.00	2,000.00
Total income	$367,964.03	$370,722.00	$366,060.00
Net profit on securities sold	65.79	....	....
	$368,029.82		
Additions to surplus	5,124.76	11,797.00	8,803.00
	$362,905.06	$358,925.00	$357,257.00

ESTIMATED COST OF ACTIVITIES FOR 1936–1937 ADOPTED BY THE COUNCIL OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, JUNE 16, 1936

Activity	Committee expense	Printing and distribution	Direct office expense	Total
Council	$ 4,200.00	....	....	$ 4,200.00
Library	8,400.00	....	....	8,400.00
A.E.C.	9,000.00	....	....	9,000.00
Sections	18,500.00	....	$ 8,885.00	27,385.00
Meetings	5,300.00	....	4,010.00	9,310.00
Divisions	2,400.00	....	4,010.00	6,410.00
Branches	7,900.00	$ 3,600.00	6,425.00	17,925.00
Admissions	......	....	6,370.00	6,370.00
Employment	3,000.00	....	420.00	3,420.00
Awards	400.00	....	....	400.00
Nominating Committee	500.00	....	....	500.00
Technical Committees	500.00	....	16,400.00	16,900.00
MECHANICAL ENGINEERING, text	......	21,650.00	10,000.00	31,650.00
Transactions	......	26,000.00	9,610.00	35,610.00
Membership List	......	5,000.00	2,160.00	7,160.00
MECHANICAL ENGINEERING, advertising	......	12,500.00	17,905.00	30,405.00
Mechanical Catalog	......	16,750.00	15,465.00	32,215.00
Publications for sale	......	18,500.00	8,630.00	27,130.00
Secretary's office	......	....	15,267.00	15,267.00
General service	......	....	25,500.00	25,500.00
Rent and depreciation	......	....	9,300.00	9,300.00
General office	......	....	5,550.00	5,550.00
Accounting	......	....	10,270.00	10,270.00
Finance committee	250.00	....	....	250.00
Constitution and By-Laws Committee	200.00	....	....	200.00
	$60,550.00	$104,000.00	$176,177.00	$340,727.00
Interest and discount	......	....	......	2,200.00
Retirement, certificates of indebtedness	......	....	......	5,000.00
Professional services	......	....	......	250.00
Staff retirement fund	......	....	......	4,080.00
U.E.T. depreciation and renewal fund	......	....	......	5,000.00
				$357,257.00

"Estimates of cost for the various activities of the Society reduced to portions of the $20 dues show that the amount of service rendered per $20 of dues received is $24.30. In addition $1.84 from each $20 is being used as a contribution to increasing our financial stability.

"This budget is presented to you for adoption, upon the recommendation of the Executive Committee. It is suggested that the question be given full consideration and thorough discussion by all parties interested and that at the close of this discussion the Council shall reach its conclusion."

The budget for 1936-1937, as finally approved, will be found elsewhere in these pages.

COMMITTEE ON SOCIETY DEVELOPMENT AUTHORIZED

Reiterating the policy adopted at the St. Louis Meeting, October 11, 1935, that "a gradual intensification of the procedures for scrutinizing candidates for admission to the Society is desirable, with special view to emphasizing quality rather than quantity of membership," the Council authorized the appointment of a Committee on Society Development, whose object it will be to prosecute aggressively a program designed to bring properly qualified members into the Society. Suggestions by J. N. Landis on a plan to stimulate the individual initiative of members of the Council, committees, and local-section officers, in submitting applications of properly qualified engineers, were adopted.

JUNIOR MEMBERS' DUES DISCUSSED

The Council discussed at length the subject of the increase from $10 to $20 of dues paid by Junior members reaching age 30. Actions by the Committee on Policies and Budget and by the Detroit Local Section, both of which made recommendations, were reviewed. A procedure for further study by the Secretary, consultation with the Detroit Section, and consideration by the Executive Committee, was voted. The decision of the Executive Committee is to be referred to local sections in Group 5, and, if all points are not reconciled, they are to be taken up at the Group Conferences of Local Section Delegates, scheduled for the autumn.

CONSTITUTION, BY-LAWS, AND RULES TO BE REVISED

For the Committee on Constitution and By-Laws, H. H. Snelling presented a comprehensive modification of the Constitution, By-Laws, and Rules of the Society, which was discussed by the Council. Revisions in the Constitution will probably be presented at the Annual business meeting of the Society in December, and submitted thereafter by letter ballot to members.

RESIGNATION OF H. R. WESTCOTT, CHAIRMAN COMMITTEE ON POLICIES AND BUDGET

The Council voted to accept with deep regret the resignation of H. R. Westcott as chairman of the Committee on Policies and Budget, and to record, for the Society, high regard and grateful appreciation of the contribution he had made to the welfare of the Society and the profession.

PROFESSIONAL DIVISIONS TO BE REGROUPED

K. H. Condit, chairman, Committee on Professional Divisions, reported that, with the exception of the Railroad Division, all divisions have accepted the plan of grouping the professional divisions into five departments; basic science, power, manufacturing, transportation, and management, and that the committee plans to proceed with this grouping. A report on the plan was published in the March issue of MECHANICAL ENGINEERING, pp. 199-201.

SEMI-ANNUAL MEETING, DETROIT, 1937

Upon recommendation of the Committee on Local Sections, the Committee on Meetings and Program concurring, it was voted to hold the 1937 Semi-Annual Meeting at Detroit, Mich.

A.S.M.E. Niagara Falls Meeting, Sept. 17-19

CURRENT practice in power plants will be the topic discussed in many of the papers to be presented September 17-19 at the Niagara Falls meeting of The American Society of Mechanical Engineers.

Because of the presence in this country of many engineers from abroad, who will be in attendance at the World Power Conference, to be held in Washington, D. C., September 7-12, the opportunity has been seized to secure papers on foreign as well as American practice, and to build up a program that will draw out discussion from engineers of all countries.

The program for the World Power Conference provides four technical inspection tours following the Washington sessions. Each of these tours is built up around a special subject—power, hydraulics, fuels, and transportation. Each will visit Niagara Falls; the power and hydraulics tours will be there on September 17 and 18, the transportation on September 17, and the fuels on September 18. For this reason, the presentation of papers at the A.S.M.E. meeting will be confined to these two days.

In addition to subjects relating to power, papers at the Niagara Falls meeting will deal with many others, including transportation, and the process and wood industries.

Details of the meeting are being completed. At present the papers and topics under discussion for the two-day meeting are as follows:

Thursday, September 17

Current Practice and Trends in American Power Plants, A. G. Christie
Superposition, E. H. Krieg
Trend of Design for Pressures From 500 to 800 Lb Pressure Steam-Electric Generating Plants, James A. Powell
German Boiler and Turbine Practice, Otto Schoene, University of Berlin
Discussion of British boiler and turbine practice
Performance of Diesel-Electric Locomotives in the Buffalo Area, J. C. Thirlwell
Mechanics of the Car Retarder, N. C. L. Brown
Latest Developments in Aircraft Power-Plant Accessories, S. W. Webster
Piston Friction in High-Speed Engines, Louis Illmer
Drum and Vacuum Drying, G. N. Harcourt
Discussion of drying equipment
Economics of Grain Handling, G. F. Butt
Safe Handling of Dangerous and Irritant Materials, M. A. Kendall.

Friday, September 18

Design and Operating Problems When Using Gas- and Oil-Fired Boilers for Standby Steam-Electric Stations, V. F. Estcourt
German Furnace Design and Combustion, Dr. Frederic Schulte, University of Berlin
American Hydraulic-Laboratory Practice, Leslie J. Hooper
Laboratory Research Projects of the Corps of Engineers, U. S. Army, Francis H. Falkner
American Hydroelectric Practice, A. C. Clogher
Canadian Hydroelectric Practice, Dr. T. H. Hogg
Grinding and Maintenance of Tungsten-Carbide Saws and Woodworking Knives, C. M. Thompson
Effect on Economy and Performance of Speed and Pressure in Sanding, H. P. Kirchner
Material Waste Reduction in Woodworking Plants, F. R. Hassler
Factors to Be Considered in Substituting One Wood for Another, E. P. A. Johnson
Recent Developments in Paints and Varnishes, R. J. Moore
Symposium on local processing industries.

Use of Term "Enthalpy" Recommended

AS announced in the July issue, page 465, the Executive Committee of the Council of The American Society of Mechanical Engineers voted at its meeting of May 21, 1936, to adopt the report of the committee, appointed January 4, 1935, by Dr. Harvey N. Davis, as authorized at the A.S.M.E. Steam Tables Research Session in December, 1934, to select an appropriate name for the thermodynamic function commonly called "total heat" or "heat content." The report follows:

(1) This committee is unanimous in recommending that the old terms "total heat" and "heat content," when used to designate the thermodynamic function defined as the internal energy plus the pressure-volume product of any working substance, be discarded. This recommendation is made because these old terms are confusing and misleading, and also because they were formerly used to represent other quantities. For example, "the total heat of saturated steam" was formerly defined as "the heat of the liquid" plus the latent heat of vaporization at the given pressure. This definition becomes clear only when a precise meaning is applied to the term "the heat of the liquid," which has been variously defined. The term "total heat" of saturated steam has usually meant the quantity of heat required to heat the liquid from 32 F to the boiling point, and then vaporize it all at *constant pressure;* but the restriction to constant pressure is too often

(*Continued on page 534*)

MOLY for WEAR

WHENEVER a product is faced with stiff operating requirements, price is not the final measure of its value or economy. "How well will it wear? How long will it last?" Its answers are the real sales-closing factors.

A manufacturer of fuel-oil pumps found that out. His competitive success, he discovered, depended on the steel he selected for rotors. It had to have exceptional hardness to resist wear and to combat the corrosive effects of various types of fuel oils.

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forgotten and the resulting confusion has been very great. Furthermore, with the properties of compressed liquid demanding more recognition as higher and higher pressures enter our engineering calculations, it becomes very important to recognize that the initial state of the liquid cannot be specified in terms of its temperature alone; hence the initial reference state of the liquid must vary with the pressure if a precise meaning is to be attached to the old term, "total heat."

The term "heat content" is fundamentally unsatisfactory because the name itself is misleading when used to represent the quantity, *internal energy plus the pressure times volume*. Furthermore, the term "heat content" is, unfortunately, sometimes used to represent the heating value of a fuel; and another meaning is occasionally given to it when it is incorrectly interpreted to mean internal energy. Therefore, in the interest of precision of statement and clarity of exposition in the classroom and in professional engineering, the committee recommends abandonment of the terms "total heat" and "heat content."

(2) The thermodynamic function, internal energy plus pressure times volume, has been in use for many years—even before the valuable work of J. Willard Gibbs; but the full significance of this function has not been readily and generally appreciated. For example the two following applications will serve to show something of its importance:

(*a*) In the steady flow of a fluid past a given section of any apparatus, the fluid carries across this section the three important forms of energy—velocity, internal, and pressure-volume—and thus the advantage of combining the last two terms as a single function is apparent. The applications of the steady flow of all sorts of fluids—liquids, gases, and vapors—become of greater engineering importance every year and the need of a suitable name for the above function thereby increases.

(*b*) Whenever any working substance undergoes a change of state *in which the pressure is maintained constant*, the quantity of heat added to this substance is equal to the difference between the final and initial values of the given function.

(3) The committee is unanimously agreed that it has been unable to find any satisfactory word (in any language) that will in itself obviously signify the thermodynamic function defined in paragraph (2); and therefore the committee recommends the use of a distinctive word which is already in considerable use in this country and abroad and whose technical meaning is determined solely by its definition.

(4) The word recommended by the committee for adoption by our Society is ENTHALPY (accented on the second syllable), a word already in use. This recommendation is made after a long discussion by the committee of the relative merits of various words some of which were suggested by members of our Society, who are not members of the committee.

(5) Of the other words considered, "thalp" was favored by five members of the committee as first choice and eight were willing to recommend its use as an authorized contraction of "enthalpy." But the recommendation of "thalp" even as a contraction, is not made by this committee, because the majority of those present at the meeting in New York on December 4, 1935, of the A.S.M.E. Special Research Committee on the Thermal Properties of Steam, showed by an informal vote that they strongly preferred the recommendation of only one word, viz., "enthalpy."

(6) It is the opinion of the committee that the use of "enthalpy" to replace the older terms, "total heat," "heat content," and also "the heat of the liquid," will remove from our technical literature one of its greatest sources of confusion.

(7) For these reasons, the committee recommends that The American Society of Mechanical Engineers (*a*) adopt this report, (*b*) use "enthalpy" in our future publications whenever it is feasible, (*c*) publish this report in "MECHANICAL ENGINEERING," and (*d*) send copies of this report to other engineering and scientific societies.

Members of the committee signing the report are: Frank O. Ellenwood, chairman, Cornell University; W. A. Carter, The Detroit Edison Company; John A. Goff, University of Illinois; P. H. Hardie, Brooklyn Edison Company; Joseph H. Keenan, Massachusetts Institute of Technology; Robert P. Kolb, North Carolina State College; L. C. Lichty, Yale University; Wallace H. Martin, Oregon State Agricultural College; B. F. Raber, University of California; Julian C. Smallwood, The Johns Hopkins University; and Milton C. Stuart, Lehigh University.

New Research-Associate Plan at Battelle Institute

The Trustees of Battelle Memorial Institute have announced a new plan to extend the scope and utility of the educational features of the Institute's basic program of scientific research. Since its inception, the policy of Battelle Memorial Institute has been to combine a program of fundamental research of general interest to industry with the applied research which it has carried on for individual companies and associations under its plan o sponsored research.

A new Division of Research Associates has been established to supplement the work in fundamental science of the regular technical staff. The purpose of this new division is to offer intensive training in practical research to the best of the younger workers in selected branches of chemistry, metallurgy, fuels, and ceramics.

The appointments as research associate will be made for one year's duration and may be extended for a second year. A research associate will be expected to devote his entire time to a research problem approved by the Director and supervised by members of the Institute staff. The results of these researches will be published in order to contribute information that will be useful to science and industry.

Appointments as research associate are open to graduates of any accredited university or college, but preference will be shown to men who have demonstrated a marked aptitude for scientific research in their industrial experience or through one or more year's graduate study. The appointment will carry an annual salary of from $1200 to $1800 depending on the training and experience of the individual. Four appointments as Battelle Research Associate will be made for the year 1936–1937.

Applications for appointment as Battelle Research Associate may be obtained from the Director, Battelle Memorial Institute, Columbus, Ohio.

A.S.T.M. Officers, 1936–1937

THE American Society for Testing Materials announces the following officers for 1936–1937, elected at its annual meeting, Atlantic City, June 30: President, A. C. Fieldner, Experiment Station Division, U. S. Bureau of Mines, Washington, D. C.; vice-president, T. G. Delbridge, manager, research and development department, The Atlantic Refining Co., Philadelphia, Pa.; member of executive committee, O. U. Cook, assistant manager, department of metallurgy, inspection, and research, Tennessee Coal, Iron, and Railroad Co., Birmingham, Ala.; H. F. Gonnerman, manager, research laboratory, Portland Cement Association, Chicago, Ill.; C. S. Reeve, manager, research development, The Barrett Co., Leonia, N. J.; F. E. Rickart, research professor of engineering materials, University of Illinois, Urbana, Ill.; and F. W. Waring, engineer of tests, The Pennsylvania Railroad Co., Altoona, Pa.

H. C. Mann, senior materials engineer, Ordnance Dept., U. S. Government, Watertown Arsenal, was awarded the Charles B. Dudley Medal for 1936, for his paper "The Relation Between the Tension, Static, and Dynamic Tests."

S.P.E.E. Elects Officers

AT the 1936 Annual Meeting of the Society for the Promotion of Engineering Education, held at Madison, Wis., early in the summer, H. P. Hammond, professor of civil engineering, Polytechnic Institute of Brooklyn, Brooklyn, N. Y., was elected president. Professor Hammond was director of Summer Schools for Engineering Teachers, 1927–1933, and associate director of investigations, 1923–1929, of the S.P.E.E.

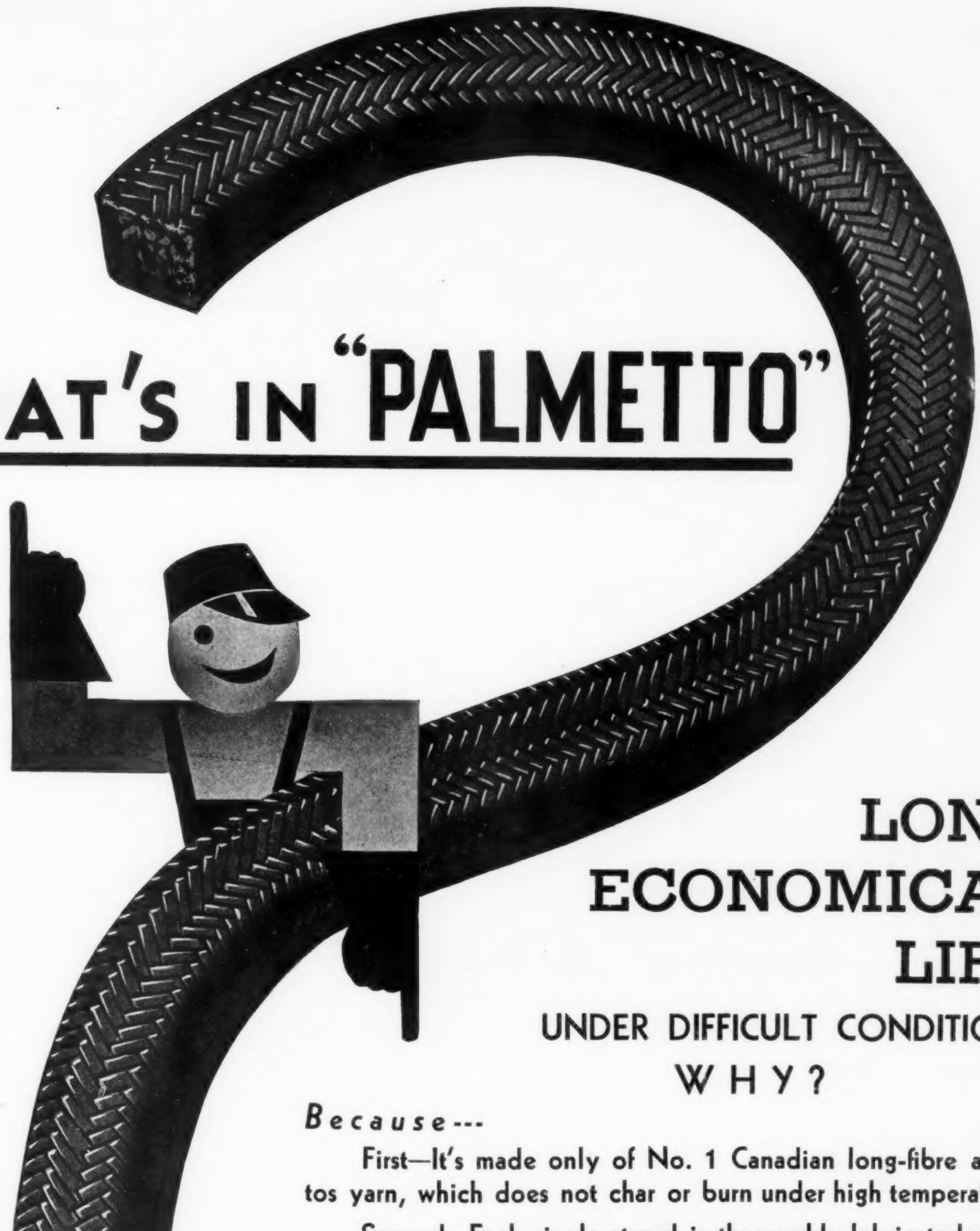
Vice-presidents elected were Ivan C. Crawford, dean, college of engineering, University of Idaho, Moscow, Idaho, and Sada A. Harbarger, assistant professor of English, The Ohio State University, Columbus, Ohio. S. W. Dudley, dean, Yale School of Engineering, New Haven, Conn., and member of the A.S.M.E., was elected to the Council.

Herman Schneider, dean, University of Cincinnati, Cincinnati, Ohio, was awarded the Lammé Medal.

The 1937 annual meeting will be held at the Massachusetts Institute of Technology, Cambridge, Mass.

(*Continued on page 536*)

WHAT'S IN "PALMETTO"



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Rackham Engineering Foundation Incorporated in Detroit

ARTICLES of incorporation of The Rackham Engineering Foundation were filed June 12, 1936, in the offices of The Michigan Corporation and Securities Commission by Standish Backus, Alex Dow, past-president, A.S.M.E., Edsel B. Ford, Bryson D. Horton, and William S. Knudsen, who are trustees of the corporation appointed for life. The new corporation will have title to the $500,000 endowment created by the Horace H. Rackham and Mary A. Rackham Fund for the benefit of the engineering professions and allied arts and sciences in the Detroit area, and for the assistance of the public in meeting engineering problems.

Under the plan adopted, the net income from the endowment will be paid to The Engineering Society of Detroit, incorporated April 15, 1936. The purposes of this society are educational and scientific. Its aims will be to aid the public to solve civic questions involving engineering problems of public interest, and finally to provide in its headquarters library service, lectures, publications, and instructions on subjects tending to increase the technical skill and social usefulness of the members. It is expected that all of the societies and groups in the engineering and allied fields together with their members will become affiliated with The Engineering Societies of Detroit.

The Rackham Engineering Foundation will have a discretionary right to permit a portion of the endowment to be used to provide permanent headquarters for The Engineering Society of Detroit. It will also have power to assign a portion of the income, not exceeding 25 per cent thereof per year, to pay the expenses of studying, investigating, and exploring the practicability or wisdom of any proposed, contemplated, or partially constructed public project in Detroit or vicinity involving engineering skill, judgment, or knowledge, and of reporting to or advising any public body, commission, or authority thereon.

The directors of The Engineering Society of Detroit are John H. Hunt, president, Harold S. Ellington, first vice-president, James W. Parker, member, A.S.M.E., second vice-president, Clair W. Dichty, secretary, Ellsworth J. Burdick, treasurer, William D. Cameron, Martin R. Fisher, Clyde R. Paton and David Segal. John W. Kennedy was appointed assistant treasurer and Ernest L. Brandt managing secretary.

The president of The Engineering Society of Detroit and the most immediate predecessor president will be ex-officio members of the Board of Trustees of the Foundation. Under such arrangement, John H. Hunt will serve as a trustee, and also Ellsworth J. Burdick until there is a predecessor president.

The late Horace H. Rackham accumulated his fortune as a director of the Ford Motor Car Company and as a result of engineering skill applied to the automotive industry. It was this fact that prompted the Board of Trustees of the Horace H. Rackham and Mary A. Rackham Fund to create this endowment.

Time-Series Charts

IN THE interests of clearness and effectiveness a tentative draft of what may become an American Standard for certain elements of time-series charts is now proposed. This proposal has been developed by Subcommittee No. 3, A. H. Richardson, chairman, of the Sectional Committee on Graphic Presentation.

Mr. Richardson's committee has made this report available in pamphlet form for the purpose of securing constructive criticism and comment. Owing to the expense involved in producing a limited number of copies, however, it is necessary for the committee to make a charge of one dollar per copy. Those desiring a copy should address the A.S.M.E. Publication Sales Department.

In its present form this code has been limited almost entirely to line charts but column and surface forms of time series charts are discussed in the appendix. As good graphic presentation does not depend on a single broad decision but on a considerable number of detailed decisions, the code is necessarily made up of a rather detailed discussion of specific points. Some of these may not in themselves seem important, but collectively, it is the decisions on such minor points which determine the success or failure of a chart.

The committee has worked on the principle that flexibility rather than standardization must be the keynote in any successful code of preferred practice. The chart must be prepared in the light of the characteristics of the data at hand and the use to which the chart is to be put; and such individual treatment, to be effective, must not do violence to the fundamental principles of graphic presentation.

In its capacity as sponsor for the Sectional Committee on Graphic Presentation the A.S.M.E. is pleased to announce that Willard Chevalier, vice-president, McGraw-Hill Publishing Company, has accepted the chairmanship of the committee, the office made vacant by the resignation of Ernest F. DuBrul.

Candidates for Membership in the A.S.M.E.

THE application of each of the candidates listed below is to be voted on after August 25, 1936, provided no objection thereto is made before that date, and provided satisfactory replies have been received from the required number of references. Any member having comments or objections should write to the secretary of the A.S.M.E. at once.

NEW APPLICATIONS

ALLEN HERBERT, Houston, Texas
BARRIE, A. O., London, W. C., England
BRODIE, GEORGE R., Philadelphia, Pa.
DUDLEY, WINSTON M., Cleveland, Ohio
HIERS, CHARLES R., Great Neck, L. I., N. Y.
HOSKINS, HAROLD V., Sydney, N.S.W., Australia
JERGER, JOSEPH, Chicago, Ill.
KETCHPEL, PAUL A., New York, N. Y.
LOO, P. Y., Nanking, China (Rt & T)
MATTSON, IRWIN F., Oriente, Cuba
MIHM, JOSEPH E., Detroit, Mich.
OLIVER, C. B., Havana, Cuba
PUTNAM, LINWOOD J., Brooklyn, N. Y.
REIHMER, LEO L., Chicago, Ill.
RICHARD, ARKLAY S., Newton Centre, Mass.
RICHARDSON, HAROLD C., Emporium, Pa.
RUSKIN, PHILIP, Winthrop, Mass. (Re)
SCHUM, LAWRENCE V., Milwaukee, Wis.
SHANNON, WILLIAM RUSSELL, East Dedham, Mass.
SHARP, ROBERT WALSH, Camaguey, Cuba
STEPHENS, J. NORRIS, Cincinnati, Ohio
TROFIMOV, LEV A., Cleveland Heights, Ohio
VOSS, GUSTAV PAUL, Chicago, Ill.
WALES, ROBERT, Havana, Cuba

CHANGE OF GRADING

Transfers from Member

HARRIS, HARRY E., Bridgeport, Conn.
SPENCER, R. L., Newark, Del.

Transfers from Junior

ERDMAN, FREDERICK S., Ithaca, N. Y.
NEWPORT VICTOR G., Forest Hills, L. I., N. Y.
WILCOXSON, LESLIE S., Ridgewood, N. J.

Necrology

THE following deaths of members have recently been reported to the Office of the Society:

BANCROFT, JOSEPH, May 6, 1936
ELY, WILLIAM G., June 14, 1936
FISKE, GEORGE I., March 29, 1936
GARANT, FRANCIS J., May 27, 1936
LEERS, ERNEST C., March 3, 1936
LOFGREN, LARS J., March 9, 1936
YOTTA, HANNIBAL A., February 6, 1936

A.S.M.E. Transactions for July, 1936

THE July, 1936, issue of the Transactions of the A.S.M.E., contains the following papers:

Boundary-Layer Flow Over Flat and Concave Surfaces (AER-58-4), by A. H. Blaisdell
The Accuracy of the Cleanliness-Factor Measurement for Surface Condensers (FSP-58-5), by P. H. Hardie and W. S. Cooper
Failure of Metals Due to Cavitation Under Experimental Conditions (HYD-58-1), by H. N. Boetcher
Plunger Lift for Pumping Deep Wells (PME-58-1), by H. W. Fletcher
The Influence of Cutting Fluids on Tool Life in Turning Steel (RP-58-11), by O. W. Boston, W. W. Gilbert, and C. E. Kraus
New Spring Formulas and New Materials for Precision Spring Scales (RP-58-12), by M. F. Sayre and A. V. de Forest
New Laboratory Data Relative to Embrittlement in Steam Boilers (RP-58-13), by F. G. Straub and T. A. Bradbury

DISCUSSION

On previously published papers by W. Hovgaard; R. E. Johnson and R. F. Gagg; E. S. Dennison; A. S. Griswold and H. E. Macomber; E. S. Pearce; and H. C. Cross and F. B. Dahle.